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Rev -

Global Precipitation Measurement (GPM) Microwave Imager (GMI) Technical Requirements

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National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland

DOCUMENT CONTROL INFORMATION

This document is controlled by the Global Precipitation Measurement (GPM) Project. Changes require the approval of the GPM Project Manager. Submit proposed changes to the GPM Project Configuration Management (CM) Office. This document will be revised per 422-PG-1410.2.1, "GPM Project CM Procedure."

GPM Configuration Management Office
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GPM Core Observatory

**Global Precipitation Measurement (GPM)
Microwave Imager (GMI)
Technical Requirements**

Approvals

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CHANGE RECORD

Note: the Document Change Record will be generated per 422-PG-1410.2.1, “GPM Project CM Procedure” and will be included in the initial formal release of this document and with each revision.

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1.0 INTRODUCTION

1.1 GLOBAL PRECIPITATION MEASUREMENT MICROWAVE IMAGER BACKGROUND

The Global Precipitation Measurement (GPM) is an international effort managed by the National Aeronautics and Space Administration (NASA) to improve climate, weather, and hydro-meteorological predictions through more accurate and more frequent precipitation measurements. The GPM Microwave Imager (GMI) will be used to make calibrated, radiometric measurements from space at multiple microwave frequencies and polarizations. GMI will be placed on the GPM Core Spacecraft together with the Dual-frequency Precipitation Radar (DPR). The DPR is two-frequency precipitation measurement radar, which will operate in the Ku-band and Ka-band of the microwave spectrum. The Core Spacecraft will make radiometric and radar measurements of clouds and precipitation and will be the central element of GPM's space segment. A second GMI may be procured and placed on a GPM constellation spacecraft in order to provide more frequent sampling of precipitation events. The measurements made by the Core will be supplemented with measurements from other microwave radiometers located on satellites launched and operated by other United States agencies and GPM international partners. A ground-based Precipitation Processing System (PPS) using science retrieval algorithms developed by GPM scientists will process the radiometric and radar measurements obtained from this collection of satellites. The data products prepared by the PPS will provide information concerning global precipitation on a frequent, near-global basis to meteorologists and scientists making weather forecasts and performing research on the global energy and water cycle, precipitation, hydrology, and related disciplines. In addition, radiometric measurements from GMI and radar measurements from the DPR will be used together to develop a retrieval transfer standard for the purpose of calibrating precipitation retrieval algorithms. This calibration standard will establish a reference against which other retrieval algorithms using only microwave radiometers (and without the benefit of the DPR) on other satellites in the GPM constellation will be compared. For additional information refer to the GPM White Paper at http://gpm.gsfc.nasa.gov/library.html.

1.2 PERFORMANCE, IMPLEMENTATION, AND VERIFICATION

The minimum requirements for performance, implementation, and their verification for the GMI are specified in this document. The GMI contractor shall specify and develop the detailed design of the GMI in accordance with these requirements. All performance requirements shall be met over the design life of the GMI. In the event that two requirements, explicit or derived, disagree by degree of stringency, the more stringent requirement shall be satisfied.

1.3 RECOMMENDATIONS FOR TAILORING

Although NASA intends to procure two identical instruments if the option is exercised, one for the Core spacecraft and one for a constellation spacecraft, the contractor may recommend to NASA implementation of unique aspects of the design that will result in improved operational performance on each spacecraft or which results in an overall cost savings for the GMI acquisition. For example, filters may be required to prevent radio frequency interference due to operation of the DPR on the Core spacecraft. The filters may not be necessary on the Constellation spacecraft, and an overall savings to NASA may be realized by deleting from one instrument the filters needed only on the GMI to be placed on the Core spacecraft.

2.0 REFERENCE DOCUMENTS AND MATERIALS

2.1 MILITARY STANDARDS AND HANDBOOKS DOCUMENTS

MIL-STD-1553-B	Digital Time Division Command/Response Multiplex Data Bus, January 1996.

2.2 NASA DOCUMENTS

GEVS-SE, Revision A	General Environmental Verification Specification for STS and ELV Payloads, Subsystems, and Components (GEVS-SE), June 1996.
NASA Technical Paper 2361	Design Guidelines for Assessing and Controlling Spacecraft Charging Effects, 1984.
NASA-STD-8719.9	NASA Technical Standard for Lifting Devices and Equipment, May 9, 2002.

2.3 GPM PROJECT DOCUMENTS

422-10-05-002	Global Precipitation Measurement (GPM) Microwave Imager (GMI) Mission Assurance Requirements.

2.4 ADDITIONAL REFERENCE MATERIALS

Microwave Remote Sensing, Active and Passive, Ulaby, F.T, Moore, R.T., and Fung, A.K, Artech House, 1981.

NASDA-HDBK-1007D	H-IIA User's Manual, Revision C, Second Edition, December 2001.

3.0 PERFORMANCE REQUIREMENTS

3.1 SENSOR CHARACTERISTICS

3.1.1 GMI Sensor Concept

3.1.1.1 Conical-Scan Radiometer (36-8)

The GMI shall be a total power type passive microwave radiometer (Ref: Ulaby, F.T., pp. 360-365), with a conical scanning antenna.

Verification: The contractor shall verify this requirement by inspection.

3.1.1.2 On-Orbit Operational Life / Design Life (36-9)

The GMI instrument shall be designed to operate on-orbit, within specification, for a minimum of 38 months. This operational duration is also referred to as design life. The 38 months includes two months of on-orbit checkout followed by 36 months of science operation.

Verification: The contactor shall verify this requirement through a probabilistic risk assessment (PRA) per the Mission Assurance Requirement document and report the analysis per CDRL DID 42.

3.1.1.3 Probability for Success (36-10)

The GMI instrument shall have, as a minimum, an 87 percent probability of operation on-orbit, within specification, for the design life (36-9).

Verification: The contractor shall verify this requirement through a PRA per the Mission Assurance Requirement document and report the analysis per CDRL DID 42.

3.1.1.4 Storage, Integration and Test, and Design Life (36-11)

The instrument shall be designed to be fully operational and meet all performance requirements following a period of up to three years from delivery to launch. This period includes two years of storage and one year for spacecraft-level integration and testing.

Verification: The contractor shall verify this requirement through analysis.

3.1.1.5 In-Flight Calibration (36-12)

The GMI design shall include an in-flight calibration subsystem employing an external calibration method. Additional requirements concerning the scanning and calibration subsystems are described in later sections.

Verification: The contractor shall verify this requirement by inspection.

3.1.2 GMI Channels

A GMI channel is defined by its center frequency, center frequency stability, pass-band bandwidth, polarization, and beamwidth. The GMI channel set is defined to be the entire complement of channels associated with the design of the GMI.

3.1.2.1 Minimum Set of Channels (36-13)

The center frequencies and bandwidths of the GMI channel set shall include the nine channels identified in Table 3-1.

Table 3-1. Required GMI Channel Set and Performance

Channel #	Center Freq[1] f_c [GHz]	CFS [MHz] (Stab +/-) (Maximum Deviation)	Pass-band Bandwidth[1] B [MHz] (Maximum)	Pol.	Integration Time[2] [ms] (for reporting NEDT)	NEDT[2] [K] (Maximum)	Antenna 3 dB beam width[3] $_{3dB}$ [degrees] (Maximum)
1	10.65	10	100	V	9.7	0.60	1.75
2	10.65	10	100	H	9.7	0.60	1.75
3	18.70	20	200	V	5.3	0.70	1.00
4	18.70	20	200	H	5.3	0.70	1.00
5	23.80	20	200	V	5.0	0.90	0.90
6	36.50	50	1000	V	5.0	0.40	0.90
7	36.50	50	1000	H	5.0	0.40	0.90
8	89.00	200	6000	V	2.2	0.70	0.40
9	89.00	200	6000	H	2.2	0.70	0.40

A. Abbreviations:

- Freq = Frequency
- Pol. = Polarization
- V = Vertical
- H = Horizontal
- stab = stability
- CFS = Center Frequency Stability
- K = Kelvin
- GHz = GigaHertz
- MHz = MegaHertz
- dB = deciBel
- NEDT = Noise Equivalent Delta Temperature = Radiometric Sensitivity
- B = Pass-band Bandwidth

B. Informational Remarks Regarding Table 3-1:

[1] The channel center frequencies and bandwidths in Table 3-1 have been selected to lie within the bands protected by NTIA allocation (Earth Exploration Satellite Service).

[2] Radiometric sensitivity is defined in Section 3.1.4. The Integration Times provided are for use in calculating NEDT. Note: These times correspond to motion through one channel 3dB beamwidth given the maximum beamwidths of Table 3-1 and an antenna rotation rate of 40 rpm. These times are not meant to suggest actual sensor integration times; these times are to be used only for NEDT calculation for comparison to required NEDT of Table 3-1.

$_{3dB} = 1.27$ [illegible] $_{3dB}$ is the half-power antenna beam width, [illegible] is the electrical wavelength, and D is the projected aperture diameter of 1.2 meter. The antenna beam widths for channels 6 -- 9 were selected in order forGMI to provide surface scene spatial resolution and spatial sampling comparable to that obtained by the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI). Further detail on channel beam width requirements is found in Section 3.1.5.2. For channels 6 -- 9, the required beam widths may be obtained by under-illumination of the antenna aperture.

Verification: The contractor shall verify by receiver tests that the operational channels are in agreement with Table 3-1.

3.1.2.2 Alternative and Additional Channels (36-14)

The contractor may propose the use of alternative and/or additional channels for the GMI channel set if their use provides improved sensor performance, improved protection from Radio Frequency Interference (RFI), or other reasons that may provide best value improvements to NASA. Proposals for alternative and/or additional channels shall include the rationale for the recommendation, and identify the center frequency, stability, width of the pass-band, polarization, calculated Noise Equivalent Delta Temperature (NEDT), antenna 3 dB beamwidths, and rationale for any use of spectrum not allocated exclusively to the Earth Exploration Satellite Service (EESS).

Verification: The contractor shall verify through analysis indicating that requirements on sensitivity (NEDT) will be met and that RFI while operating outside EESS bands will not degrade accuracy.

3.1.2.3 Use of Allocated Spectrum (36-15)

To minimize the possibility of radio frequency interference, all recommendations for alternative and/or additional GMI channels, shall be chosen when possible for the pass-bands of those channels to coincide with (or fall within) the National Telecommunications and Information Agency (NTIA) bands allocated for passive remote sensing. A list of relevant NTIA bands allocated for EESS passive remote sensing is located at http://www.ntia.doc.gov/osmhome/allochrt.html (1996).

Verification: The contractor shall verify through design and spectrum tests on the receiver.

3.1.2.4 NASA Approval for Alternative and Additional Channels (36-16)

Any recommendations for changes to the channels identified in Table 3-1 shall only be implemented after formal NASA approval.

Verification: The contractor shall verify by inspection that recommendations are provided to appropriate NASA officials.

3.1.2.5 Dedicated Receivers (36-17)

Each channel shall have a corresponding dedicated receiver.

Verification: The contractor shall verify this requirement by inspection.

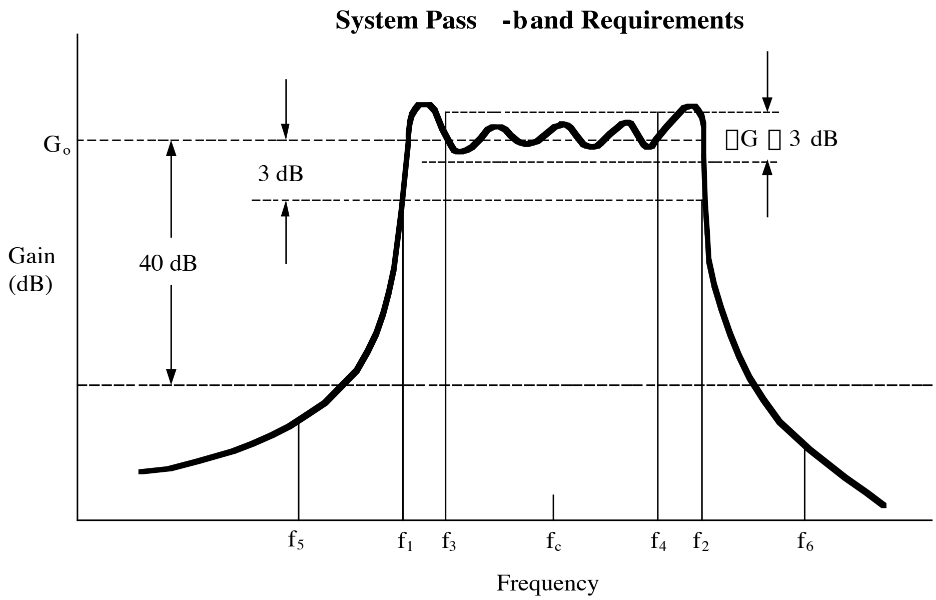
3.1.2.6 Concurrent Scene Processing (36-18)

Scene signals shall be processed concurrently on all channels.

Verification: The contractor shall verify this requirement by demonstration.

3.1.3 <u>Channel Pass-Band</u>

Figure 3-1 illustrates the notation for the GMI channel pass-band requirements.



<u>Bandwidth (B):</u>	**<u>Gain Variation Within Central 75 Percent of Pass-Band:</u>**	**<u>Out-of-Band Rejection:</u>**
B = Bandwidth = $f_2 - f_1$ $G(f_1) = G_o$–3 dB $G(f_2) = G_o$–3 dB $f_1 = f_c - 0.5$ B $f_2 = f_c + 0.5$ B	$f_3 = f_c - 0.75$ (0.5 B) $f_4 = f_c + 0.75$ 0.5 B) for $f_3 <= f <= f_4$, $\|G - G_o\| <= 1.5$ dB	$f_5 = f_c - 0.75$ (B) $f_6 = f_c + 0.75$ (B) for $f <= f_5$ and $f >= f_6$, $G <= G_o - 40$ dB

where f_c is the pass band center frequency located equidistant from the 3 dB pass -band frequencies f_1 and f_2, and G_o is the mean system gain within the central 75 percent of the pass-band.

Figure 3-1. Example of Channel Pass-Band in Compliance with Requirements

Figure 3-1. Example of Channel Pass-Band in Compliance with Requirements

3.1.3.1 Pass-Band Bandwidth and Frequency Dependent Gain Variation (Pass-Band Ripple)

The pass-band bandwidth is defined as $B = f_2 - f_1$, and illustrated in Figure 3-1. The pass-band requirements apply to the end-to-end response of the receiver from the antenna input to the detector output.

3.1.3.1.1 Pass-Band Bandwidth (36-19)

The pass-band bandwidth of each GMI channel shall be no greater than the values listed in Table 3-1.

Verification: The contractor shall verify this requirement by demonstrating the receiver response over the frequency band of interest. Separate measurements of antenna feed and receiver contributions shall be used to verify pass-band characteristics.

3.1.3.1.2 Peak-to-Peak Gain Variation (36-20)

The maximum peak-to-peak gain variation, (delta)G, of the central 75 percent (frequencies between f_3 and f_4 in Figure 3-1) of each GMI channel pass-band shall be less than 3 dB. In the event that the receiver employs a double side band superheterodyne technique with an intermediate frequency at baseband, the guard band region about DC shall be stated. The peak-to-peak gain variation requirement does not apply to the DC guard band region.

Verification: The contractor shall demonstrate the receiver response over the frequency band of interest. The measurement's amplitude accuracy shall be 0.5 dB (rms) or better.

3.1.3.2 Out-of-Band Rejection

3.1.3.2.1 Out-of-Band Gain Roll-Off (36-21)

The out-of-band system gain roll-off of every channel shall be sufficiently steep so that at the points whose frequencies are greater than 0.75 times the Radio Frequency (RF) pass-band bandwidth away from the center frequency (i.e., all frequencies less than f_5 and all frequencies greater than f_6 in Figure 3-1), the system gain shall be at least 40 dB below the gain at the center frequency.

Verification: The contractor shall demonstrate the receiver response over the frequency band of interest.

3.1.3.2.2 Out-of-Band Signals (36-22)

For every GMI channel, all performance specifications shall be met in the presence of any expected on-orbit out-of-band (outside of the 3 dB channel pass-band) signal. Known sources of out-of-band signals include those arising from the operation of the DPR (transmitting frequencies at 13.6 GHz and 35.55 GHz) and spacecraft communications system transmitting at 2287.5 MHz and receiving at 2106.4 MHz.

Verification: The contractor shall demonstrate the receiver response at the frequencies and power levels of known emitters. The contractor shall demonstrate the receiver response with the DPR and communications systems activated.

3.1.3.3 Channel-to-Channel Isolation (36-23)

The channel-to-channel isolation for all channels of different center frequencies shall be greater than or equal to 40 dB at any frequency.

Verification: The contactor shall, through demonstration, provide the level of radio frequency leakage measured between channels.

3.1.3.4 Frequency Stability (36-24)

The center frequency of each GMI channel shall be maintained within the stability values (both above and below the specified frequency) as denoted in Table 3-1.

Verification: The contactor shall demonstrate receiver performance 10 degrees C beyond expected on-orbit temperature range of receiver. The rms frequency accuracy of demonstration shall be 10 percent, or less, of the frequency stability requirement listed in Table 3-1. The contractor shall provide analysis for expected end-of-life performance.

3.1.3.5 Gain Stability

Short term is defined to be within the time period of a scan. Long term is defined as the time period greater than one scan and extends throughout the entire lifetime of the instrument, which includes the storage, integration and testing periods prior to launch, and the on-orbit operating period.

3.1.3.5.1 Short Term Gain Stability (36-25)

The GMI channel gain shall be stable over the short term such that the radiometric measurement accuracy, sensitivity, and all performance requirements are met.

Verification: The contractor shall demonstrate by recording instantaneous noise power over many scans and recording the statistics.

3.1.3.5.2 Long Term Gain Stability (36-26)

Under all operational conditions, any changes in the GMI radiometer channel gain shall not cause that channel to operate outside of its linear dynamic range, nor cause the analog-to-digital converter to overflow.

Verification: The contractor shall demonstrate the noise power level input to the analog-to-digital converter.

3.1.4 Radiometric Sensitivity

The radiometric sensitivity (NEDT) is the minimum detectable change of the microwave power (in brightness temperature units) incident at the antenna aperture. It is the end-to-end resolution of the radiometer, including all contributing factors. NEDT is defined as the standard deviation of the radiometer measurement. The radiometric sensitivity values in Table 3-1 are defined for the corresponding integration times. These times and their corresponding radiometric sensitivities are not meant to suggest actual implemented integration times and sensitivities.

3.1.4.1 Minimum Radiometric Sensitivity Requirements (13-212)

The radiometric sensitivity of each GMI channel shall not exceed the values listed in Table 3-1. The radiometric sensitivity, for determining requirement satisfaction, shall be consistent with the integration times provided in Table 3-1.

Verification: The radiometric sensitivity of each channel of the GMI instrument shall be measured under the following conditions:

a. The feedhorn shall view a 300 K ± 5 K constant brightness temperature.
b. The integration and sample times as well as other operating conditions, such as instrument's ambient temperature range, shall be the same as if it were in on-orbit operation. The per-sample radiometric sensitivity shall be reported and analysis may be used to report the radiometric sensitivities consistent with the integration times provided in Table 3-1.
c. The radiometric sensitivity shall be referenced to the antenna (main reflector) aperture.
d. Sufficient number of samples shall be taken to ensure the uncertainty of the derived radiometric sensitivity is less than 0.05 K.

Any factors which affect the radiometric sensitivity defined at the antenna aperture, such as reflection losses and non-ideal calibration target emissivity etc., that are not included in the measurement of the temperature sensitivity shall be determined by measurements and/or analysis. The determination of the radiometric sensitivity defined at the antenna aperture shall properly account for these factors through analysis.

3.1.4.2 Radiometric Sensitivity Reporting (13-213)

The contractor shall report the radiometric sensitivities for each channel of the proposed design at the corresponding integration time provided in Table 3-1.

Verification: The contractor shall verify through inspection of a documented report.

3.1.4.3 Contributing Factors for Radiometric Sensitivity (36-27)

The radiometric sensitivity shall include the following phenomena:

a. White (Gaussian) noise, both from the internal receiver noise and the incident antenna temperature.
b. System gain fluctuations, due to thermal or other causes (e.g., 1/f, power supply ripple induced, etc.).

c. Analog-to-digital conversion quantization noise.
d. Noise introduced during the calibration measurements.

Verification: The contractor shall provide analysis and/or demonstration reflecting that these sources are included.

3.1.4.4 Reference Antenna Temperature (36-30)

The reference radiometric antenna temperature for reporting the GMI radiometric sensitivity shall be 300 K.

Verification: The contractor shall verify through inspection of a documented report.

3.1.4.5 Dynamic Range (36-31)

The minimum dynamic range of each GMI channel, including the effects of quantization, shall be 3 to 340 K.

Verification: The contractor shall demonstrate through test and analysis. Extrapolation in the analysis may be employed for demonstrating dynamic range extension to 3 K. The contractor shall demonstrate that the entire radiometric dynamic range lies within the dynamic range of the analog-to-digital converter.

3.1.5 Antenna System

3.1.5.1 Antenna Type (36-32)

The GMI antenna shall consist of a single offset-fed parabolic reflector.

Verification: This shall be verified through inspection of the sensor.

3.1.5.2 Antenna Beam Width

The antenna beam width is defined as the half-power total width (the total width between two 3 dB points) for each GMI channel and is the arithmetic average of the two beam widths in the two principal planes.

3.1.5.2.1 Maximum Antenna Beam Widths (36-33)

The antenna beam widths shall not exceed the values denoted in Table 3-1.

Verification: The contractor shall measure the radiation patterns of the main polarization of each channel of the GMI instrument and shall compute an average of the two principal planes of the patterns at two different frequencies, preferably one at mid-frequency in the upper half of the channel and one at mid-frequency in the lower half of the channel.

The measurement shall be of sufficient accuracy such that:

a. The main-beam electrical bore sight shall be determined accurately so as to demonstrate that the pointing accuracy requirements are met.

b. The dynamic range of the pattern measurement shall be such that the measurement is capable of determining side-lobe levels to 50 dB, or lower, below the main lobe.

A minimum of four planes (cuts) of the antenna radiation pattern shall be measured. They are:

1. Principal plane (of symmetry of the reflector)
2. Orthogonal plane
3. 45 degree plane
4. 135 degree plane

3.1.5.3 Beam Shape (36-34)

The antenna beam width in any plane containing the axis of maximum gain for a given GMI channel shall be within 15 percent of that channel's beam width.

Verification: The contractor shall demonstrate through analyses of the antenna pattern tests.

3.1.5.4 Beam Efficiency (36-35)

The antenna main beam efficiency shall be greater than 90 percent for channels 1 through 9. For a given channel, the beam efficiency is the ratio of the power of the main polarization received through the main beam diameter to the total power received by the antenna. The total power received by the antenna includes the power in the main beam as well as all the side lobes. Total power includes both the power of the main polarization and the cross-polarization. The main beam diameter is defined to be 2.5 times the half-power beam width listed in Table 3-1.

Verification: The contractor shall demonstrate through analyses of the antenna pattern tests. The error in the result shall not exceed 1.0 percent. The contractor shall employ as many antenna measurements as deemed necessary for ensuring the error is within 1.0 percent.

3.1.5.5 Polarization Requirements

The Earth incidence angle, $\square_i$, is the angle between the Earth's normal vector and the propagation vector measured at the point where the propagation vector meets the Earth's surface. The horizontal, h, and vertical, v, polarization vectors are defined by Equations 3-1 and 3-2 respectively and are shown in Figure 3-2.

$$\mathbf{h} = \frac{\mathbf{k} \times \mathbf{n}}{|\mathbf{k} \times \mathbf{n}|} \qquad \mathbf{v} = \mathbf{h} \times \mathbf{k} \qquad \mathbf{k} = -\mathbf{r}$$

Equation 3-1 **Equation 3-2** **Equation 3-3**

Equation 3-1 **Equation 3-2** **Equation 3-3**

where n is the geodetic unit normal at the Earth's surface, r is the bore sight unit vector for a given GMI channel, and k is the unit vector parallel but in the direction opposite to r and defined in Equation 3-3.

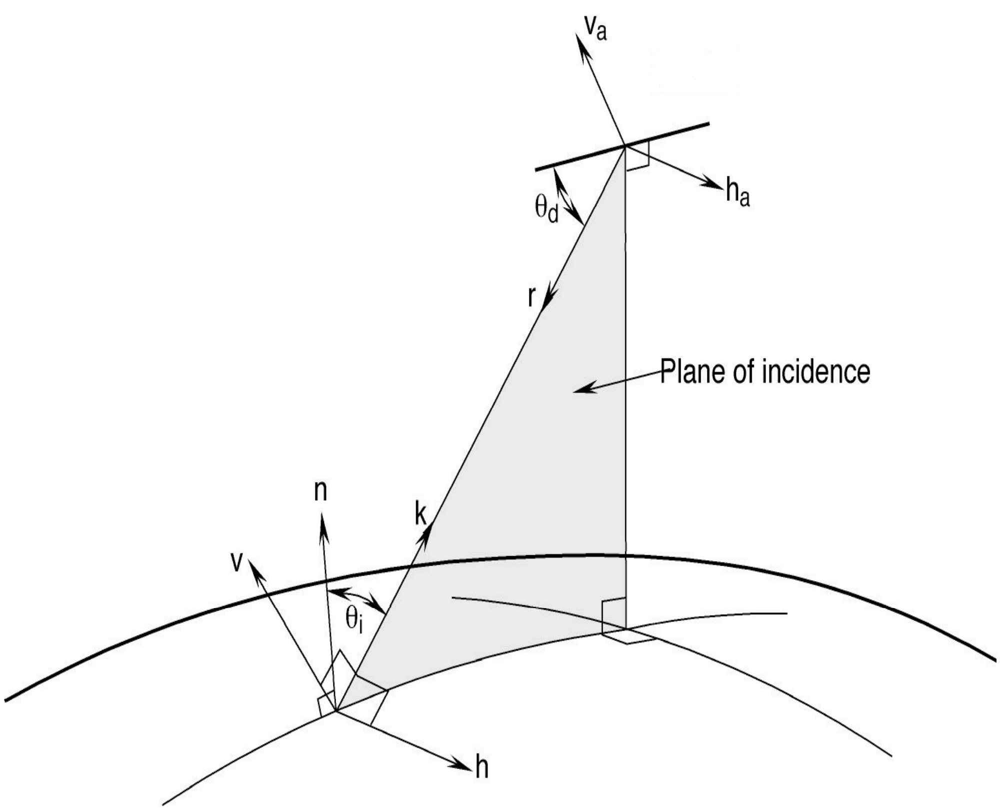


Figure 3-2. Definition of Earth Incidence Angle, Bore-Sight Depression Angle, and Polarization Vectors

Figure 3-2. Definition of Earth Incidence Angle, Bore-Sight Depression Angle, and Polarization Vectors

Figure 3-2 identifies the Earth incidence angle (EIA), θ_i, and the antenna bore sight depression angle, θ_d. All beam positions are defined at the midpoint between the beam's half power points, i.e., at the electrical bore sight. For the purposes of this document, the antenna electrical bore sight for each channel is defined as the midpoint between the beam's half-power points. The subscript 'a' refers to the polarization vectors at the antenna.

3.1.5.5.1 Polarization Requirements and Beam Position within Scan (36-36)

The linear polarization of each channel shall correspond to that denoted in Table 3-1. The polarization requirements (36-37, 36-38, and 36-39) shall apply to all beam positions of the scan.

Verification: The contractor shall verify this requirement through demonstration, measurement, and analysis. The contractor shall include the effect of potential off-nadir angle wobble movement over the scan.

3.1.5.5.2 Vertical Polarization Alignment (36-37)

Each vertically-polarized beam shall have its polarization direction lie in the plane of incidence to within ±0.5 degrees (see Figure 3-2).

Verification: The contractor shall verify by demonstration and analyses of antenna pattern measurements.

3.1.5.5.3 Horizontal Polarization Alignment (36-38)

Each horizontally polarized beam shall have its polarization direction lie normal to the plane of incidence to within ±0.5 degrees (see Figure 3-2).

Verification: The contactor shall verify by demonstration and analyses of antenna pattern measurements.

3.1.5.5.4 Cross-Polarization Isolation (36-39)

The integrated cross-polarization ratio shall be less than 1 percent for channels 1 through 5 and less than 3 percent for each of channels 6 through 9. The cross-polarization ratio is defined to be the total cross-polarization power inside the half-power beam width divided by the total power of the antenna.

Verification: The contractor shall demonstrate through analyses of the antenna pattern measurements performed in the cross-polarization. The cross-polarization measurements shall be of sufficient accuracy and detail to demonstrate that the requirement on total cross-polarization power are met. The same frequencies and measurement methods described in Maximum Antenna Beam Widths (36-33) verification shall be used for the cross-polarization pattern tests.

3.1.6 Scanning Requirements

3.1.6.1 Scanning Requirements General (36-40)

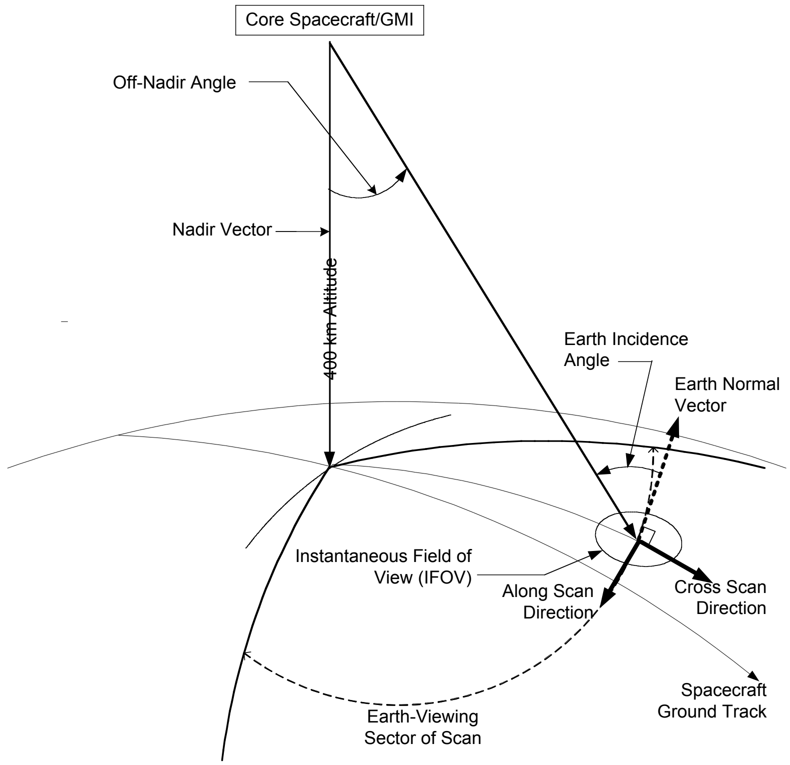


Figure 3-3. Scan Geometry of the GMI Radiometer

Figure 3-3. Scan Geometry of the GMI Instrument

The GMI design shall be consistent with the conical scanning configuration shown in Figure 3-3. Cross-scan is defined as the direction along the Earth's surface perpendicular to the azimuthal direction of the circular scan pattern of the antenna beam. Along-scan is defined as the direction along the Earth's surface parallel to the azimuthal direction of the circular scan pattern of the antenna beam.

Verification: The contractor shall verify this requirement by inspection.

3.1.6.2 Conical Scan System (4-714)

The antenna beams shall scan conically; that is, the scan motion of each of the beams generates a circular cone whose axis is parallel to the nadir vector.

Verification: The contractor shall verify by inspection.

3.1.6.3 Constant Antenna Rotational Rate (4-715)

The antenna shall rotate at a constant angular rate as observed from above the instrument, Earth nadir viewing, in performing the conical scan.

Verification: The contractor shall specify and document the rotational rate. The contractor shall verify this requirement through measurement.

3.1.6.4 Rotational Rate Tolerances (4-716)

During the Sensor Operational Mode, the angular rate of rotation shall deviate by no more than ±0.3 percent. For periods exceeding a single scan, the angular rate of rotation shall deviate by no more than ±1.0 percent.

Verification: The contractor shall verify through demonstration.

3.1.7 Scan Drive Assembly

3.1.7.1 Scan Drive Assembly Lifetime (36-532)

Requirement: The scan-drive assembly shall meet the design life of the instrument (36-9).

Verification: The contractor shall verify through life-test or past on-orbit performance the scan-drive assembly expected life. The contractor shall verify the function of the scan drive assembly by testing it at temperature extremes 10 degrees C beyond the range of expected flight temperatures. In accordance with GEVS-SE, Rev. A, the recommended goal for the life test is to achieve a 25% margin on mission life. The contractor shall provide a probability for achieving the 38-month required operation in conjunction with the PRA CDRL DID 42. The verification and probability reporting shall be representative of the rotation rate designed for GMI on-orbit operation.

3.1.7.2 Earth Viewing Sector

The continuous rotation of the antenna about the nadir vector defines a 360 degree arc, with portions of the arc dedicated to Earth-viewing (data taking), calibration, and non-measurement functions, including providing buffer areas to prevent antenna side lobes from contaminating measurement signals. The center of scan is defined to be the orientation of the antenna such that its Instantaneous Fields of View (IFOV) lies co-incident with the spacecraft ground track.

3.1.7.2.1 Earth-Viewing Sector Size (36-41)

The Earth-viewing sector shall provide a minimum of 130 degrees and a maximum of 145 degrees continuous viewing arc.

Verification: The contractor shall verify through design documentation and through demonstration.

3.1.7.2.2 Earth-Viewing Sector Centered on Spacecraft Ground Track (36-42)

Design of the instrument shall allow installation of the instrument on the spacecraft and provide equal Earth-viewing sectors to either side of the spacecraft ground track (i.e., a minimum of 65 degrees of Earth-viewing sector on each side of the orbital plane). (The spacecraft will provide a mounting location that will provide a viewing sector with a clear Earth-viewing sector field-of-view.)

Verification: The contractor shall verify through design documentation and through analysis.

3.1.7.3 Earth Scene Viewing

The IFOV is defined in the along-scan and cross-scan directions as the 3 dB contour of the antenna beam projected onto the Earth's surface.

3.1.7.3.1 Reporting IFOVs (36-43)

For each channel, the contractor shall report the IFOV in the along-scan and cross-scan directions for both 407 km and 635 km spacecraft altitude.

Verification: The contractor shall verify through analyses and measured antenna patterns.

3.1.7.3.2 Reporting Variation of IFOV with Scan Position (36-44)

If there is more than 5 percent variation in the IFOV for any channel over the scan, the contractor shall report the minimum, maximum, and average values in the along-scan and cross-scan directions for that channel.

Verification: The contactor shall verify through analyses.

3.1.7.3.3 Derivation of IFOVs (36-45)

The contractor shall provide the derivation of the IFOV values, including all assumptions.

Verification: The contractor shall verify by providing documentation of analyses.

3.1.7.3.4 Description of 90 Percent Energy Contour (36-46)

The contractor shall provide a detailed description of the 90 percent energy contour of the projected antenna beam for each GMI channel, weighted over the channel pass-band, at the center of scan, and referenced by two orthogonal directions corresponding to the along-scan and cross-scan directions.

Verification: The contractor shall verify through analyses of antenna-beam-pattern and receiver-response measurements.

3.1.7.4 Spatial Scene Sampling

3.1.7.4.1 Spatial Scene Sampling General (36-531)

The integration time and sampling time for each channel shall be suggested by the contractor and agreed to by NASA. The sampling time is the integration time plus any time duration of non-observation necessitated by the sample electronics and process.

Verification: This requirement shall be verified by written concurrence from NASA and demonstration of GMI performance.

3.1.7.4.2 Sampling Times for All Channels (36-48)

Ratios of sampling times for all channels shall be expressible by an integer multiple.

Verification: The contractor shall verify through demonstration and analysis that the sampling times for all channels are related by integer multiple.

3.1.7.4.3 Along-Scan Direction

3.1.7.4.3.1 Along-Scan Sampling for Channels 1 Through 7 (36-47)

For channels 1 through 7, in the along-scan direction there shall be at least 2.0 samples per IFOV (3 dB antenna beam width).

Verification: The contractor shall verify through demonstration and analysis the acquisition of at least 2.0 samples per channel IFOV for channels 1 through 7.

3.1.7.4.3.2 Along-Scan Sampling for Channels 8 and 9 (36-49)

For channels 8 and 9 in the along-scan direction there shall be at least 1.0 samples per IFOV (3 dB antenna beam width).

Verification: The contractor shall verify through demonstration and analysis the acquisition of no less than 1.0 samples per channel IFOV for channels 8 and 9.

3.1.7.4.4 Cross-Scan Direction

3.1.7.4.4.1 Cross-Scan Sampling for Channels 1 Through 7 (36-50)

For channels 1 through 7 in the cross-scan direction there shall be at least 1.0 samples per IFOV (3 dB antenna beam width).

Verification: The contractor shall verify through demonstration and analysis the acquisition of no less than contiguous spatial coverage in the cross-scan dimension for channels 1 through 7.

3.1.7.4.4.2 Cross-Scan Sampling for Channels 8 and 9 (36-51)

For channels 8 and 9 in the cross-scan direction there shall be at least one sample within a distance of twice the IFOV (3 dB antenna beam width).

Verification: The contractor shall verify through demonstration and analysis the acquisition of no less than 50 percent spatial coverage in the cross-scan dimensions for channels 8 and 9.

3.1.7.5 Beam Pointing Requirements

3.1.7.5.1 Instrument Optical Alignment Reference (36-52)

The GMI shall contain an optical alignment reference that provides a capability for alignment of the instrument with external references.

Verification: The contractor shall verify through inspection.

3.1.7.5.2 Absolute Beam Pointing (36-53)

Absolute beam pointing requirements shall apply from the beam center to the instrument optical alignment reference.

Verification: The contractor shall verify by providing measurements with respect to the instrument optical alignment reference.

3.1.7.5.3 Relative Beam Pointing (36-54)

Relative beam pointing requirements shall apply from the beam center to the beam center of channel 7.

Verification: The contractor shall verify by providing measurements with respect to the beam center of channel 7.

3.1.7.5.4 Off-Nadir Angle

The GMI off-nadir angle, θ_n, is defined in Figure 3-2, as $\theta_n = 90 - \theta_d$, where θ_d is the antenna bore sight depression angle, in degrees.

3.1.7.5.4.1 Off-Nadir Angle Reference Channel (36-55)

The off-nadir angle of channel 7 with respect to the vertical vector of the instrument optical alignment reference shall be set to a value between 48.3 and 48.7 degrees.

Verification: The contractor shall verify through measurement, and analysis for predicting on-orbit performance, that the off-nadir angle requirement is satisfied.

3.1.7.5.4.2 Off-Nadir Angle Multiple Feedhorns (36-56)

For a design employing multiple feedhorns at the same frequency, the contractor shall choose to specify, with NASA's approval, off-nadir angles different from that stated in requirement 36-55.

Verification: The contractor shall verify through measurement, and analysis for predicting on-orbit performance, that the multiple feedhorn off-nadir angles meet the mutually agreed values.

3.1.7.5.4.3 Off-Nadir Angle Other Channels (36-57)

The off-nadir angle for each GMI channel shall be set to a value within 0.10 degrees of the off-nadir angle of channel 7, or within 0.10 degrees of the angles approved by NASA for multiple feedhorns per requirement 36-56.

Verification: The contractor shall verify through measurement, and analysis for predicting on-orbit performance, and shall document in report form.

3.1.7.5.5 Absolute Beam Pointing Error (36-58)

For all channels, the error in absolute antenna beam pointing shall not exceed 0.12 degrees in the cross-scan and along-scan directions.

Verification: The contractor shall verify through measurement, and analysis for predicting on-orbit performance, that absolute antenna beam pointing error is not exceeded.

3.2 CALIBRATION

3.2.1 <u>On-Orbit Calibration</u>

3.2.1.1 <u>Hot and Cold Calibration (36-60)</u>

During each scan, in particular, each complete rotation of the antenna, a hot calibration measurement and a cold calibration measurement shall be made by each channel.

Verification: The contractor shall verify through demonstration.

3.2.1.2 <u>Calibration Load Sampling (36-61)</u>

Each calibration measurement shall consist of a minimum of two samples, with each sample having the same integration time as that used for Earth scene measurements.

Verification: The contractor shall verify through demonstration.

3.2.1.3 <u>On-Orbit Calibration Accuracy (36-83)</u>

The absolute calibration accuracy shall be 1.5 K or better with stability of 0.5 K or better for all GMI channels over the required dynamic range.

Verification: The contractor shall verify through the Sensor Calibration (requirements 36-527, 36-88, and 36-89) and the Conversion of Pre-Launch to On-orbit Calibration (requirement 36-90) and Calibration Error Analysis (requirements 36-91 and 36-92).

3.2.1.4 System Nonlinearity (36-84)

System nonlinearity, defined as the deviation from the ideal linear response, shall not exceed 0.5 K for each measurement channel. Note: ideal linear response refers to a linear relationship between radiance at the antenna input and system output in units of volts or digital counts. System linearity shall apply over a brightness temperature dynamic range of 3 K to 340 K.

Verification: The contractor shall verify through the Sensor Calibration (requirements 36-527, 36-88, and 36-89) and the Conversion of Pre-Launch to On-Orbit Calibration (requirement 36-90).

3.2.1.5 Hot Calibration Observation

3.2.1.5.1 Use of Hot Load for Calibration (36-64)

During the hot calibration period of each scan, the feedhorns shall view a calibration target termed the hot calibration load.

Verification: The contractor shall verify by inspection of design and inspection of implementation.

3.2.1.5.2 Placement of Hot Load (36-65)

The on-orbit hot calibration load shall consist of a non-rotating calibration target that intercepts the line-of-sight between the feedhorns and the main reflector as the feedhorns pass beneath the hot calibration load during each scan.

Verification: The contractor shall verify by inspection of design and inspection of implementation.

3.2.1.5.3 Hot Load Physical Temperature Range (36-68)

The on-orbit hot calibration load shall have a physical temperature between 250 K and 330 K. Thermal control, stabilization, and gradient minimization of the hot calibration load may be implemented either passively or actively at the vendor's discretion.

Verification: The contractor shall verify in accordance with Hot Load Performance Tests (requirement 36-73).

3.2.1.5.4 Hot Load Physical Temperature Spatial Variation (36-66)

The on-orbit spatial variation in physical temperature over the hot load shall not exceed 0.5 K.

Verification: The maximum range of temperature variation shall be verified in accordance with requirement 36-73. The spatial variation of physical temperature as indicated by the temperature transducers (36-69) shall not exceed 0.5 K within the complete set of sensors.

3.2.1.5.5 Hot Load Physical Temperature Temporal Variation (36-67)

The on-orbit temporal variation in physical temperature of the hot load shall not exceed 0.1 K over one scan period.

Verification: The maximum physical temperature temporal variation shall be verified in accordance with requirement 36-73. The temporal variation of physical temperature as indicated by the temperature transducers (36-69) shall not exceed 0.1 K between scans.

3.2.1.5.6 Hot Load Temperature Measurement (36-69)

The temperatures of the hot calibration load shall be monitored using a minimum of five NIST traceable temperature transducers and shall be reported at least once per scan.

Verification: The contractor shall verify this requirement by inspection and demonstration.

3.2.1.5.7 Hot Load Observation Calibration Error (36-70)

The component of calibration error associated with the hot load observation shall not exceed 0.5 K. This error is the sum total of all sources of error associated with the hot load observation.

Verification: The contractor shall verify in accordance with Calibration Error Analysis (requirements 36-91 and 36-92).

3.2.1.5.8 Hot Load Calibration Error Analysis (36-71)

An error analysis shall be conducted describing the primary sources of the hot calibration error and their quantitative contribution to the sum total error. The error sources shall include non-unity emissivity of the target and temperature gradients across and within the target.

Verification: The contractor shall verify in accordance with Calibration Error Analysis (requirements 36-91 and 36-92).

3.2.1.5.9 Hot Load Performance Tests (Verification) (36-73)

The behavior of the hot calibration load shall be measured and analyzed to predict its on-orbit performance.

Verification: The hot target shall be measured and analyzed to ascertain at minimum the following:

1. Physical temperature including temperature range, temperature temporal variation, and temperature spatial variation (i.e. radial and axial gradients) over the aperture under simulated orbital thermal conditions. This shall include all possible operational solar incidence angles on the hot load.
2. Emissivity at all channel frequencies and its spatial variation over the surface.

3. Reflection characteristics between the hot target and the feedhorns in terms of Voltage Standing Wave Ratio (VSWR) or return loss.

3.2.1.6 Cold Calibration Observation

3.2.1.6.1 Cold Calibration View of Cold Space (36-74)

During on-orbit cold calibration period, the feedhorns shall view cold space.

Verification: The contractor shall verify by inspection of design and inspection of implementation.

3.2.1.6.2 Use of Cold Sky Reflector (36-75)

The on-orbit view of cold space shall be accomplished using a non-rotating cold sky reflector providing an unobstructed refection of cold space (~2.7 K) to the feedhorns.

Verification: The contractor shall verify by inspection of design and inspection of implementation.

3.2.1.6.3 Placement of Cold Sky Reflector (36-76)

The cold sky reflector shall intercept the line-of-sight between the feedhorns and the main reflector as the feedhorns pass beneath the cold sky reflector during each scan.

Verification: The contractor shall verify by inspection of design and inspection of implementation.

3.2.1.6.4 Cold Target Observation Calibration Error (36-77)

The component of calibration error associated with the cold target observation shall not exceed 1.2 K. This error is the sum total of all sources of error associated with the cold target observation.

Verification: This shall be verified in accordance with the Cold Calibration Reflector Measurements and Analyses (requirement 36-81) and with the Calibration Error Analyses (requirements 36-91 and 36-92).

3.2.1.6.5 Cold Calibration Error Analysis (36-78)

An error analysis shall be conducted describing the primary sources of the cold calibration error and their quantitative contribution to the sum total error. The error analysis shall include expected energy interception from the Sun, Earth, and spacecraft from cold sky reflector sidelobes for all operational sun incidence angles.

Verification: This shall be verified in accordance with the Cold Calibration Reflector Measurements and Analyses (requirement 36-81) and with the Calibration Error Analyses (requirements 36-91 and 36-92).

3.2.1.6.6 Cold Sky Reflector Orientation (36-80)

The orientation of the cold sky reflector's view to cold space shall be selected to be consistent with the requirement for the Core spacecraft to periodically perform 180 degree yaw maneuvers to ensure that one side of the spacecraft is consistently oriented away from the Sun and towards cold space.

Verification: The contractor shall verify through analyses given spacecraft attitude, configuration, and orbital information provided by NASA and in accordance with the Cold Calibration Reflector Measurements and Analyses (requirement 36-81).

3.2.1.6.7 Cold Calibration Reflector Measurements and Analyses (Verification) (36-81)

The uncertainty in the knowledge of the cold reference radiometric temperature (during cold calibration) shall be 0.75 K or less.

Verification: The contractor shall demonstrate, by laboratory measurements or analyses, or a combination thereof, that the uncertainty in the knowledge of the cold reference radiometric temperature (during cold calibration mode) shall be 0.75 K or less. The error due to noise power emanating outward from the instrument, including feedhorn(s), and reflected by the cold sky reflector back into the feedhorn(s) shall be quantified.

3.2.1.6.8 Cold Sky Reflector Unobstructed Field-of-View (36-82)

The contractor shall demonstrate that the cold sky view is unobstructed by the spacecraft.

Verification: The contractor shall demonstrate by test or analysis that there are no intrusions into the cold sky reflector's field-of-view by the solar panel or other portions of the spacecraft.

3.2.1.7 <u>Antenna Physical Temperature Monitoring</u>

3.2.1.7.1 Antenna Temperature Measurement at Three Locations (36-62)

The physical temperature of the reflecting surface of the main antenna shall be continuously monitored during the Sensor Operational Mode in at least three locations using National Institute of Standards and Technology (NIST) traceable temperature measurement devices. These measurements shall be telemetered in the GMI Housekeeping Data Record.

Verification: The contractor shall verify through demonstration.

3.2.1.7.2 Antenna Temperature Measurement Accuracy (36-63)

The antenna physical temperature measurement shall be accurate to ±1 K.

Verification: The contractor shall verify through analysis.

3.2.2 Calibration Algorithm

3.2.2.1 Development of Calibration Algorithm (36-85)

The contractor shall develop calibration algorithms necessary for translating the on-orbit raw data into brightness temperatures of a given sample.

Verification: The contractor shall verify through the Sensor Calibration (requirements 36-527, 36-88, and 36-89) and the Conversion of Pre-Launch to On-Orbit Calibration (requirement 36-90).

3.2.2.2 Temperature Range for Calibration Algorithm (36-86)

The calibration algorithms shall cover the entire operating physical temperature range of the GMI instrument while in orbit.

Verification: The contractor shall verify through the Sensor Calibration (requirements 36-527, 36-88, and 36-89) and the Conversion of Pre-Launch to On-Orbit Calibration (requirement 36-90).

3.2.2.3 Pre-Launch and On-Orbit Algorithm Relationship (36-87)

The algorithm shall delineate the relationship between pre-launch laboratory calibration test data and on-orbit calibration measurements.

Verification: The contractor shall verify through the Sensor Calibration (requirements 36-527, 36-88, and 36-89) and the Conversion of Pre-Launch to On-Orbit Calibration (requirement 36-90).

3.2.3 Sensor Calibration (Verification)

3.2.3.1 Sensor Calibration (36-527)

The contractor shall perform a system-level calibration of the sensor during environmental tests which replicate the on-orbit operating environment.

Verification: The contractor shall perform a sensor calibration consisting of two elements:

2. Feedhorn calibration, which establishes the relationship between brightness temperature input at the feedhorn aperture and the radiometer digital count (or voltage) output.
3. Antenna main reflector calibration, which provides the relationship between the antenna temperature input at the main reflector aperture to the radiometer digital count output. The antenna temperature at the antenna aperture is here defined as the average (over different directions within the main beam) brightness temperature.

3.2.3.2 Feedhorn Calibration (Verification) (36-88)

Each channel of the sensor shall be calibrated in a procedure termed 'feedhorn calibration' and detailed in the following verification requirement.

Verification: The feedhorn calibration shall be conducted by measuring the radiometer output with a variable, simulated Earth target as input whose brightness temperature is varied from 340 K to 80 K and which envelops the field-of-view of the feedhorns. The feedhorn calibration shall be performed under simulated nominal orbital conditions for the GMI instrument, with the calibration targets maintained as close to their on-orbit configuration as possible. A cold target may be substituted for the cold calibration sub-reflector. The feedhorn calibration shall be repeated for three instrument physical temperatures values, one at the expected nominal orbital value, one at the expected orbital high value, and one at the expected orbital low value. The reference point for the instrument physical temperature shall be the scan drive assembly.

3.2.3.3 Antenna Main Reflector Calibration (Verification) (36-89)

The antenna main reflector shall be calibrated.

Verification: Antenna main reflector calibration shall include the ohmic and return losses of the main reflector, non-zero emissivity of the main reflector, as well as the antenna beam efficiency and side lobe characteristics.

3.2.3.4 Conversion of Pre-Launch to On-Orbit Calibration (Verification) (36-90)

The contractor shall demonstrate through laboratory testing and analyses that the overall calibration accuracy meets the requirements specified when GMI is used in its orbital configuration.

Verification: The analyses shall include: conversion from pre-launch laboratory tests with simulated cold calibration targets to actual on-orbit cold target conversion of the calibration from the feedhorn aperture calibration method to the antenna aperture calibration required on-orbit. The analyses shall also show the degradation effects on the calibration accuracy due to aging of the target, thermal gradient and cycling, as well as side-lobes and obstructions of objects near the GMI antenna and calibration subsystems.

3.2.4 Calibration Error Analysis (Verification)

3.2.4.1 Pre-Launch Calibration Error Analyses (Verification) (36-91)

An error analysis/budget for the GMI pre-launch calibration, which includes all relevant error sources to the pre-launch calibration, shall be prepared.

Verification: The error analysis/budget for the GMI pre-launch calibration shall be included as a minimum:

- Calibration target temperature uniformity and measurement error
- Non-blackbody emissivity of calibration target

- Imperfect coupling between the feedhorn and calibration targets (e.g., undesired power entering the feedhorn)
- Cross-polarization coupling errors
- Antenna feedhorn spillover
- Feedhorn to reflector alignment errors
- Antenna reflector emissions
- Quantization error
- The effect of incident radiation outside of the feedhorn antenna’s 90 percent energy contour (sidelobe effects)
- Non-linear radiometer transfer function
- Any calibration algorithms (such as antenna pattern correction) which may be required to meet calibration accuracy requirements.

3.2.4.2 On-Orbit Calibration Error Analysis (Verification) (36-92)

An error analysis/budget for the GMI on-orbit calibration, which includes all relevant error sources to the on-orbit calibration, shall be prepared.

Verification: The error sources shall include, as a minimum, those identified in the verification of requirement 36-91.

4.0 IMPLEMENTATION REQUIREMENTS

4.1 ELECTRICAL REQUIREMENTS

4.1.1 Power Subsystem

4.1.1.1 Operational Power Service / Redundant Power Sources (36-93)

For GMI operational power service, the spacecraft will provide two separately switched power sources to GMI. GMI shall operate within specification with power applied to either or both of these sources. GMI shall isolate its power inputs so that power is not applied back onto the other spacecraft source.

Verification: The contractor shall verify this requirement by testing.

4.1.1.2 Source Voltage Operating Range (36-94)

GMI shall operate within performance specifications for any primary source voltage from 21 V to 35 V DC.

Verification: The contractor shall verify through functional tests at 21 V, 28 V, and 35 V DC input voltage. The contractor shall show by analysis that the requirement is met over the continuous source voltage range of 21 to 35 V.

4.1.1.3 Source Voltage Survival Range (36-95)

GMI shall survive, without damage or degradation, and for unlimited duration, source voltages from 0 to 40 V DC.

Verification: The contractor shall verify through analysis and testing of the appropriate power subsystem of the instrument.

4.1.1.4 Reversed Power Leads (36-96)

GMI shall survive, without damage or degradation, and for unlimited duration, reversed polarity operating voltages.

Verification: The contractor shall verify this requirement by analysis or through demonstration. Flight hardware need not be subjected to this demonstration.

4.1.1.5 Turn-On Transient Current (36-97)

GMI operational power from the spacecraft power system will be sourced through Solid State Power Controllers (SSPC). The SSPCs provide the functions of circuit protection and power switching. The rated load current of the SSPCs employed for GMI power sourcing is 10 A. GMI transient turn-on currents shall not exceed a value representing 80% of the Minimum Trip Limit curve of Figure 4-1.

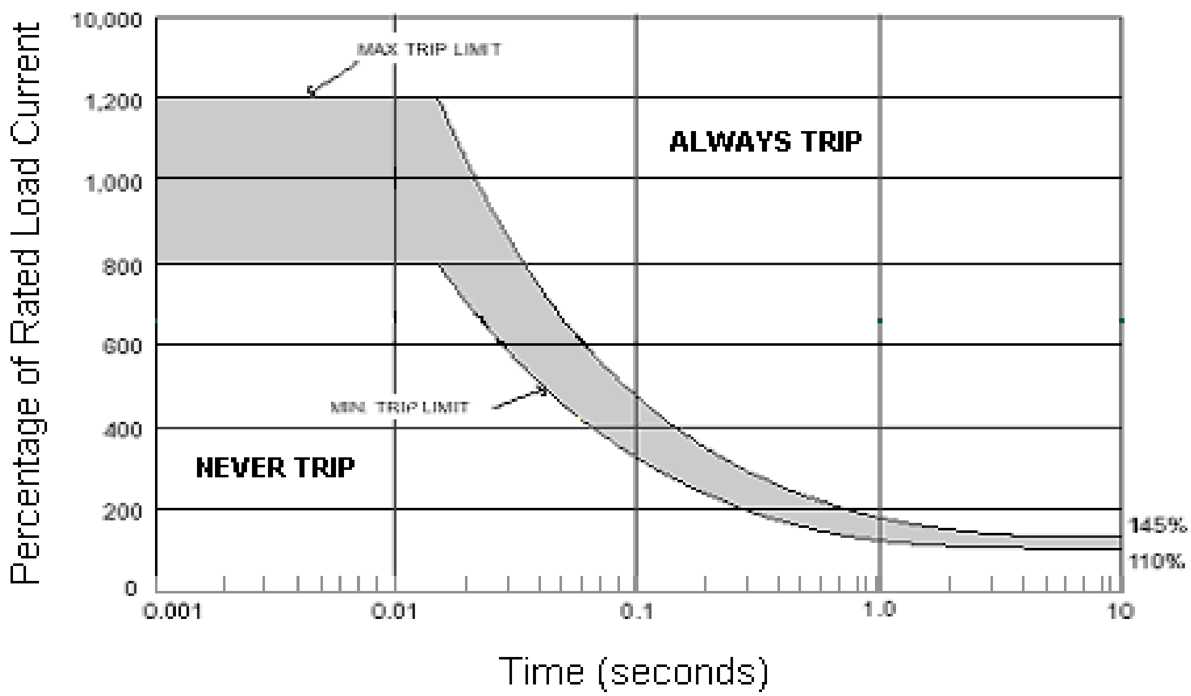


Figure 4-1. Solid State Power Controller Trip Characteristics

Verification: The vendor shall verify the turn-on transient requirement by test. Testing shall measure the current and voltage waveform at the prime power input of GMI from the start of transient until steady state. All possible operational power transients shall be tested. The characteristics of the power supply and switch used for testing shall be consistent with a direct energy transfer power system and a solid-state power controller.

4.1.1.6 Power Bus Single Event Transients (36-99)

During operational transients, GMI current shall not exceed 125 percent of the maximum current drawn during the GMI Operational Mode. The rate of change of operational transients shall not exceed 20 mA/us.

Verification: The contractor shall verify by test.

4.1.1.7 Turn-Off Transient (36-100)

The peak voltage of transients induced on the power source due to turn-off of the load shall not exceed +40 V nor drop below 0 V with respect to ground.

Verification: The contractor shall verify this requirement by testing.

4.1.1.8 Power Removal (36-102)

The GMI shall not be damaged by sudden removal of power during ground or on-orbit operation.

Verification: The contractor shall verify this requirement by testing.

4.1.1.9 Survival Heater Power Service / Redundant Power Sources (36-103)

In addition to the redundant operational power service, the spacecraft will provide redundant power service to the GMI survival heaters with the same characteristics as the operational power service. GMI shall maintain its internal temperatures within survival range with power applied to either or both of the survival heater sources. GMI shall isolate its survival heater power inputs so that power is not applied back onto the other source.

Verification: The contractor shall verify this requirement by testing.

4.1.1.10 Power Consumption (36-104)

The total power drawn, from both operational power and survival heater power sources, from the spacecraft shall not exceed 90 W orbital average in the Sensor Operational Mode. When operational power service is removed, the total power drawn shall not exceed 48 W orbital average from the survival heater power service.

Verification: The contractor shall verify by test that for all instrument modes the power consumption at 21 V, 28 V, and 35 V DC does not exceed the specified limits. The contractor shall include analysis for verifying that power consumption over the continuous source voltage range of 21 to 35 V DC does not exceed the specified limit.

4.1.2 GMI Data Records (GDR)

4.1.2.1 Data Record Categories (36-533)

The primary data from the GMI instrument shall be separated into two categories: (1) Science Data Records and (2) Housekeeping Data Records.

Verification: This requirement will be verified by demonstration.

4.1.2.2 GMI Science Data Record Content (36-105)

The GMI Science Data Record (GSDR) for each antenna measurement scan shall, as a minimum, contain the following information:

- Time tag representing start of scan
- Raw data counts for each GMI measurement position of each GMI channel
- Sensor calibration data
- Scan index number

The GMI contractor may recommend additional information and data to be included in the GDR.

Verification: The contractor shall verify through demonstration that required elements are incorporated within the GMI Science Data Record (GSDR).

4.1.2.3 GMI Housekeeping Data Record Content (36-106)

The GMI Housekeeping Data Record (GHDR) record shall, as a minimum, contain the following information:

- Time tag representing start of scan
- Data necessary to assess performance
- Data necessary to compute radiometric sensitivity
- Antenna physical temperature measurement
- Scan index number

The GMI contractor may recommend additional information and data to be included in the GHDR.

Verification: The contractor shall verify through demonstration that required elements are incorporated within the GHDR.

4.1.3 Command and Data Handling

4.1.3.1 Data Interface (36-107)

The operational command and telemetry interface with the spacecraft shall be through a redundant MIL-STD-1553-B data bus with the GMI configured as a remote terminal (RT).

Verification: The contractor shall verify this requirement through integrated testing of the GMI with the spacecraft.

4.1.3.2 Science Data Telemetry (36-108)

GMI shall output a science data record once per complete scan rotation.

Verification: The contractor shall verify this requirement through demonstration.

4.1.3.3 Science Data Telemetry Buffering (36-109)

The instrument shall be capable of storing at least one complete science data record in addition to simultaneously generating a second record.

Verification: The contractor shall verify this requirement through demonstration.

4.1.3.4 Science Data Telemetry Rate (36-110)

In the GMI Operational Mode (36-528 and related section), the GMI shall produce an orbital average science data rate not to exceed 24 kbps.

Verification: The contractor shall verify this requirement through analysis and demonstration.

4.1.3.5 Housekeeping Data Telemetry (36-111)

The GMI instrument shall produce housekeeping data telemetry which the spacecraft bus controller will read over the MIL-STD-1553-B interface separate from the science data. The housekeeping record shall consist of engineering data used for monitoring the health and performance of the instrument.

Verification: The contractor shall verify this requirement through demonstration.

4.1.3.6 Housekeeping Data Telemetry Buffering (36-112)

The instrument shall be capable of storing at least one complete housekeeping data record in addition to simultaneously generating a second record.

Verification: The contractor shall verify this requirement through demonstration.

4.1.3.7 Housekeeping Data Telemetry Rate (36-113)

The GMI housekeeping telemetry rate shall not exceed 1 kbps.

Verification: The contractor shall verify this requirement through analysis and demonstration.

4.1.3.8 Spacecraft-Monitored Telemetry (36-114)

The instrument shall use up to 5 [TBR] signal (0 to 5 V) lines for the purpose of providing analog and discrete logic telemetry to the spacecraft. The signals chosen for this telemetry shall represent instrument critical health and status data, e.g., critical temperature data. The spacecraft will monitor this telemetry without regard to the instrument mode. The spacecraft-monitored telemetry will not be incorporated into the GMI data records but will be handled through the spacecraft data path.

Verification: The contractor shall verify this requirement through demonstration.

4.1.4 Timing

4.1.4.1 Time Tagging of Data Records (36-115)

GMI shall include a time tag within each GDR and GHDR. The time shall represent the first sample position of the scan. The time reported in the tag shall not exceed ±1.0 ms from the actual time (referenced to the spacecraft) of the first scan position.

Verification: The contractor shall verify this requirement through demonstration.

4.1.4.2 Timing Index Pulse on Scan (36-116)

GMI shall provide a timing index pulse to a test port accessible during ground evaluation and testing. The timing index pulse shall have a known, and constant, temporal relation to the first sample position of the scan. The timing index pulse will not be provided over an interface to the spacecraft; it is strictly to be used during evaluation and testing during ground activities.

Verification: The contractor shall verify this requirement through demonstration.

4.1.4.3 Spacecraft Time Reference (36-117)

The GMI shall accept a 1.0 Hz synchronizing pulse signal to be used in conjunction with the spacecraft time broadcast on the MIL-STD-1553-B bus to establish time throughout the GPM spacecraft. The 1.0 Hz signal will be provided from redundant inputs on the spacecraft interface. Under normal conditions one input will be active at a time. The 1.0 Hz signal will be provided using a dedicated standard LVDS interface. The 1553 message will contain the official spacecraft time effective at the next pulse.

Verification: The contractor shall verify this requirement by demonstration.

4.1.5 Grounding

4.1.5.1 Primary Input Power Isolation (36-118)

The GMI instrument primary power and primary power returns shall be isolated from the component chassis by greater than 1×10^6 Ohm DC resistance. Power converter secondary windings shall be isolated from primary power by greater than 1×10^6 Ohm DC resistance. The spacecraft will provide a single-point chassis ground reference for the primary power.

Verification: The contractor shall verify this requirement by measuring the resistance between each primary input lead, chassis, and secondary power.

4.1.5.2 Structural and Mechanical Grounding (13-211)

All principal structural elements shall be bonded by methods that assure a direct-current (DC) resistance of less than 1.0 Ohm at each joint. Grounding straps may be used to satisfy this requirement. This requirement applies to mechanisms, including hinges and slip rings. For structural grounds carried through a slip ring, at least two slip rings shall be dedicated to the structural ground path. Refer to NASA technical Paper 2361 for design guidelines.

Verification: The contractor shall verify this requirement by measurement and analysis.

4.1.5.3 Grounding of External Surfaces (36-119)

External surfaces shall satisfy the following requirements, in accordance with NASA Technical Paper 2361:

1. Isolated conductors must be grounded with less than 1×10^6 Ohms to the structure.
2. Materials applied over a dielectric area shall be grounded at the edges and shall have a surface resistivity less than 1×10^9 Ohms/square.
3. Materials applied over a conductive substrate shall have bulk resistivities less than 1×10^{11} Ohms cm.
4. The measured DC electrical resistance between all layers of thermal blankets and chassis shall be a maximum of 10 Ohms.

Verification: The contractor shall verify this requirement by measurement and analysis. In particular, the contractor shall measure the resistance of each blanket layer to the instrument ground reference once the blanket is installed. The contractor shall measure the resistance of accessible surfaces to ground and shall employ analysis to ensure that all external surfaces, regardless of accessibility to resistance measurement, satisfy the requirement.

4.1.6 Electromagnetic Interference (EMI) / Electromagnetic Compatibility (EMC)

4.1.6.1 EMI/EMC General (36-120)

The GMI instrument shall conform to the electromagnetic compatibility (EMC) requirements delineated in the General Environmental Verification Specification for STS and ELV Payloads, Subsystems, and Components (GEVS-SE) Revision A, Section 2.5.

As a minimum, the vendor shall perform the following EMC tests on the GMI instrument:
CS01, CS02, CS06, CE03, RS03, and RE02

It is recommended that testing be performed at the component and subsystem levels of assembly in addition to the required instrument-level tests. The term instrument-level shall include any separately mounted and powered subsystems, as for example, a momentum wheel assembly.

Verification: The contractor shall verify this requirement through testing in accordance with the relevant GEVS-SE EMC test.

4.1.6.2 Conducted Susceptibility (CS) (4-717)

The GMI shall not malfunction or exhibit degraded performance in the presence of anticipated spacecraft power system noise.

Verification: The GMI shall be subjected to the following tests and shall operate without malfunction or degraded performance.

CS01 and CS02: A sine wave having an amplitude and frequency indicated in the table below shall be superimposed upon the instrument input power leads.

Test	Frequency Range	Level

CS01	30 Hz to 50 kHz	3.0 Vrms
CS02	50 KHz to 400 MHz	1.0 Vrms

CS06: Positive and negative transients having amplitude, as shown in Figure 4-2 below, shall be superimposed upon each of the instrument input power leads.

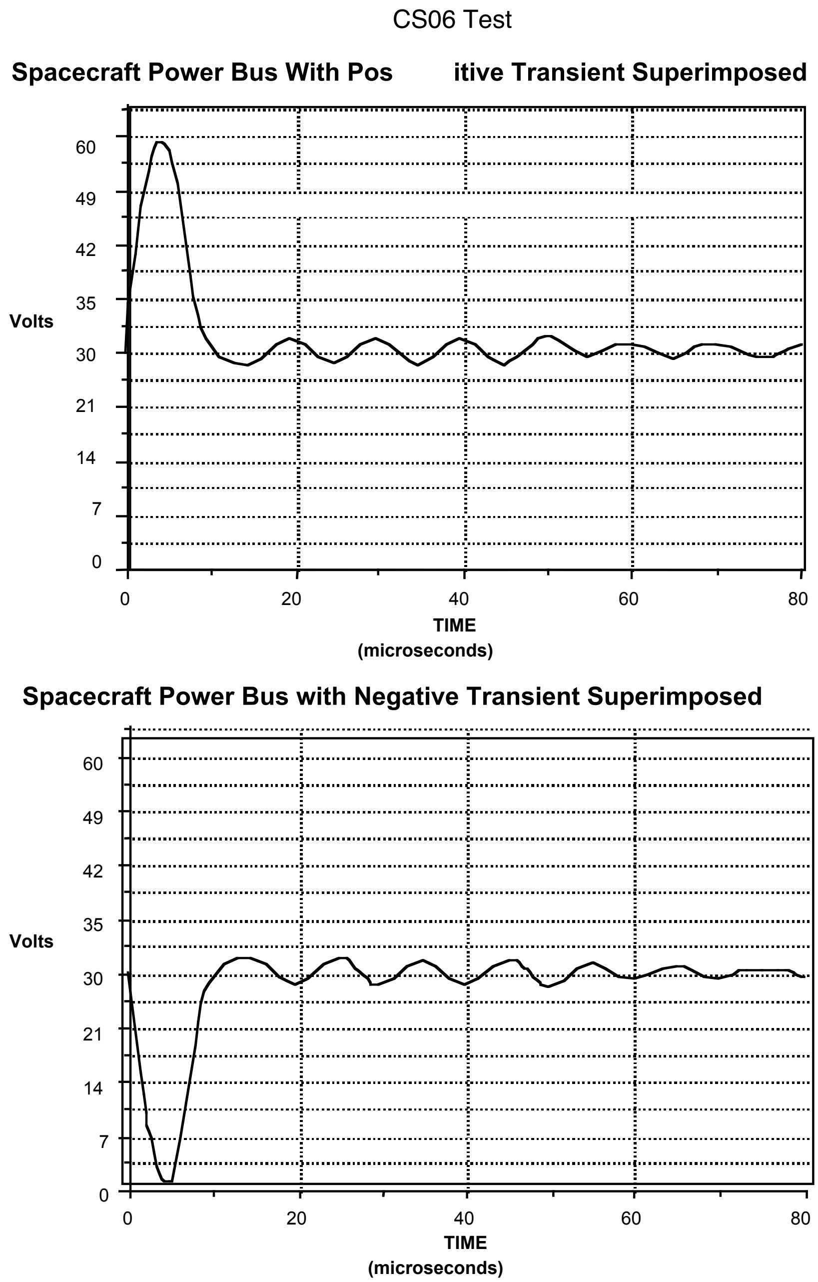


Figure 4-2. Conducted Susceptibility CS06 Testing

4.1.6.3 Conducted Emissions (CE) (4-718)

The GMI shall not produce electromagnetic emission on its input power lines beyond the limits specified in GEVS-SE.

Verification: The GMI shall be subjected to narrowband testing per CE03 on all primary input power and return lines to the instrument. Applicable test parameters and limits are as follows for narrowband Conducted Emissions. Narrowband Conducted Emissions tests shall be performed independently on both the Primary DC Input Power and Input Return leads.

Narrowband test limits:

Limit	Frequency Range	Bandwidth
120 dBuA (1.0 A rms)	30 Hz to 450 Hz	5 Hz
120 dBuA to 50 dBuA (0.32 mA rms)	450 Hz to 20 kHz	5 Hz
50 dBuA to 20 dBuA (1 uA rms)	20 KHz to 2 MHz	500 kHz
20 dBuA	2 MHz to 30 MHz	5 kHz
20 dBuA	30 MHz to 50 MHz	50 kHz

The GMI shall be subjected to Common Mode Conducted Emissions testing using the same procedures as the narrowband CE01/03 but with the Primary DC Input Power and Return leads combined together.

Common Mode test limits:

Limit	Frequency Range	Bandwidth
50 dBuA (0.32 mA rms)	30 Hz to 20 kHz	5 Hz
50 dBuA to 20 dBuA (10 uA rms)	20 kHz to 2 MHz	500 Hz
20 dBuA	2 MHz to 30 MHz	5 kHz
20 dBuA	30 MHz to 50 MHz	50 kHz

4.1.6.4 Radiated Susceptibility (RS) (4-719)

The GMI shall satisfy all operational requirements in the presence of the anticipated on-orbit electromagnetic radiation environment. Known spacecraft emission sources are the S-Band communications transmitter at 2287.5 GHz, the DPR Ku band radar at 13.6 GHz, and the DPR Ka band radar at 35.55 GHz.

Verification: The GMI shall be subjected to the following radiated electromagnetics fields and the tests shall be conducted in accordance with RS03 of GEVS-SE. Specific modifications to the test may be made with NASA approval. In particular, modifications for testing within the GMI channel passbands may be affected with NASA approval. No undesirable response, malfunction, or degradation of performance shall be produced in the GMI instrument when subjected to the following transmitted frequencies and electrical field strengths:

Frequency Range	Test Level
14 kHz-2 GHz	2 Volts/Meter (GEVS-SE)
2 GHz-12 GHz	5 Volts/Meter (GEVS-SE)
12 GHz-18 GHz	20 Volts/Meter (GEVS-SE)
18 GHz-40 GHz	20 Volts/Meter (GEVS-SE)
2287.5 MHz	20 (TBR) V/m GPM Core Spacecraft Transmitter
13.6 GHz	TBD V/m GPM DPR-Ku radar
35.55 GHz	TBD V/m GPM DPR-Ka radar

4.1.6.5 <u>Radiated Emissions (RE) (4-720)</u>

Radiated electromagnetic emissions from the GMI shall not exceed the limits found within Figure 4-3 for 'Components and Instruments'. The GMI shall be insensitive to its self-emission.

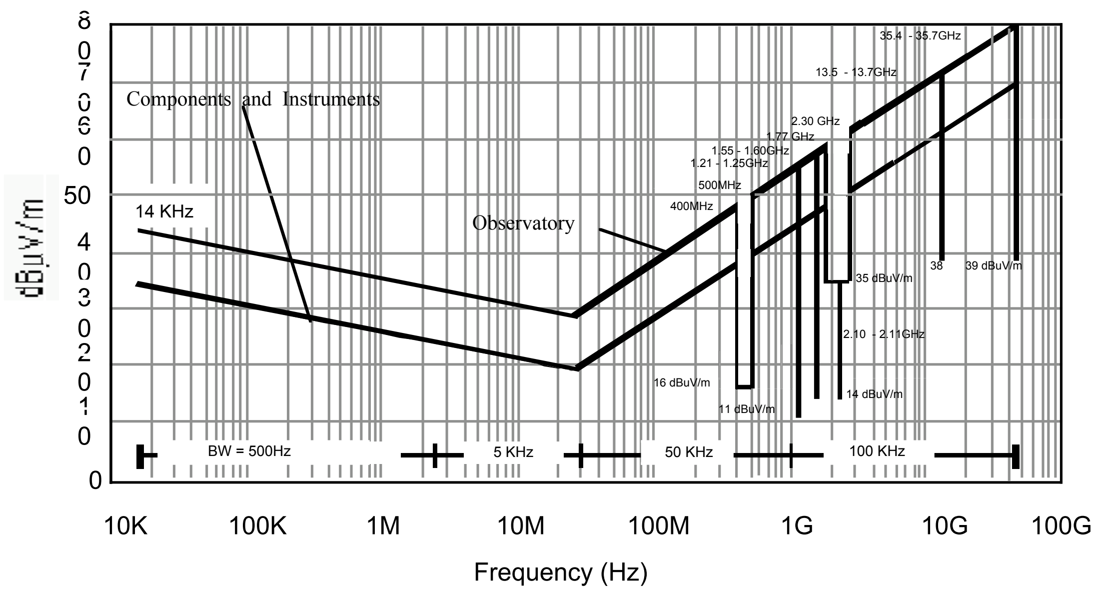


Figure 4-3. Radiated Narrowband Emission Limits for the Core Observatory and Instruments

Verification: The GMI shall be tested for radiated electromagnetic emissions in all of its powered modes. The GMI shall not exceed the limits found within Figure 4-3 for 'Components and Instruments'. Tests shall be conducted in accordance with the procedures of RS02 of GEVS-SE.

4.2 MECHANICAL REQUIREMENTS

4.2.1 <u>Envelope on Launch Vehicle and on Spacecraft (36-121)</u>

The GMI instrument shall be contained within specified Core spacecraft envelopes for three situations: 1) stowed (pre-deployed configuration) during launch, 2) during nominal instrument operations (post-deployed configuration), and 3) during the deployment sequence with respective envelopes shown in Figure 4-4, Figure 4-5, and Figure 4-6.

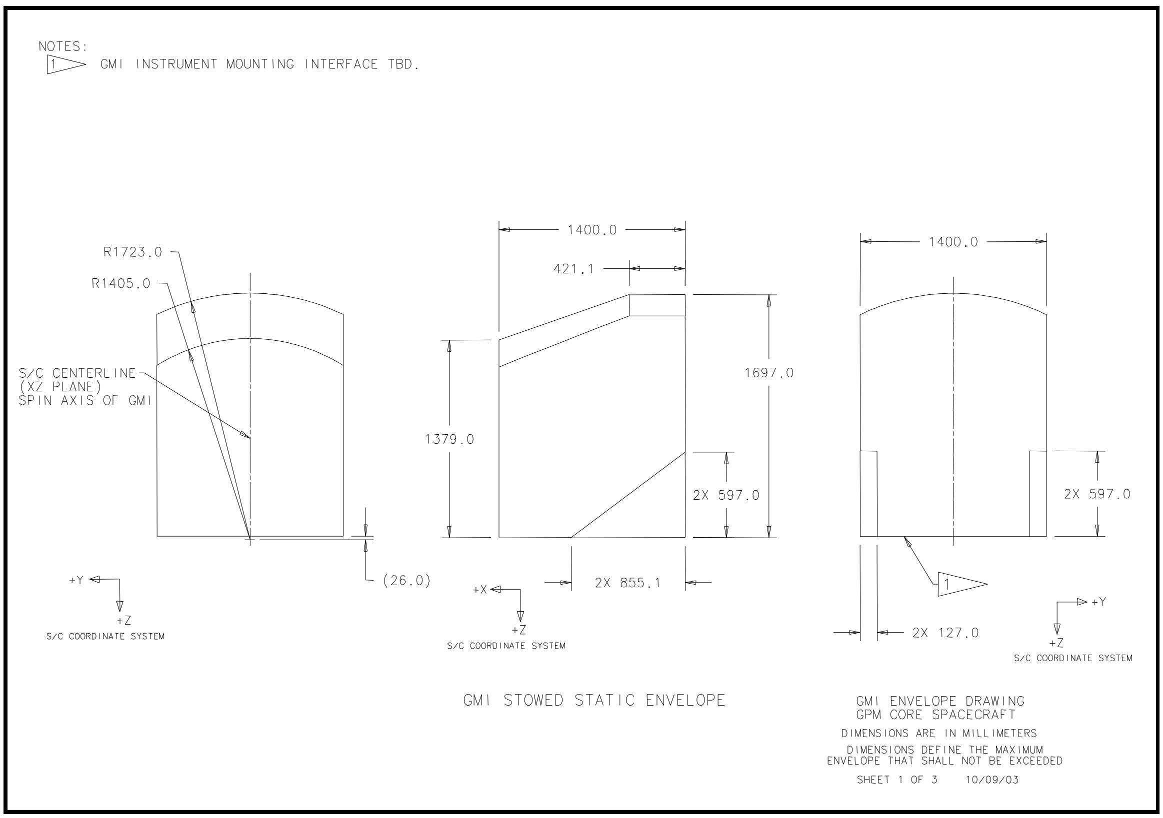


Figure 4-4. Available Envelope During Stowed Configuration

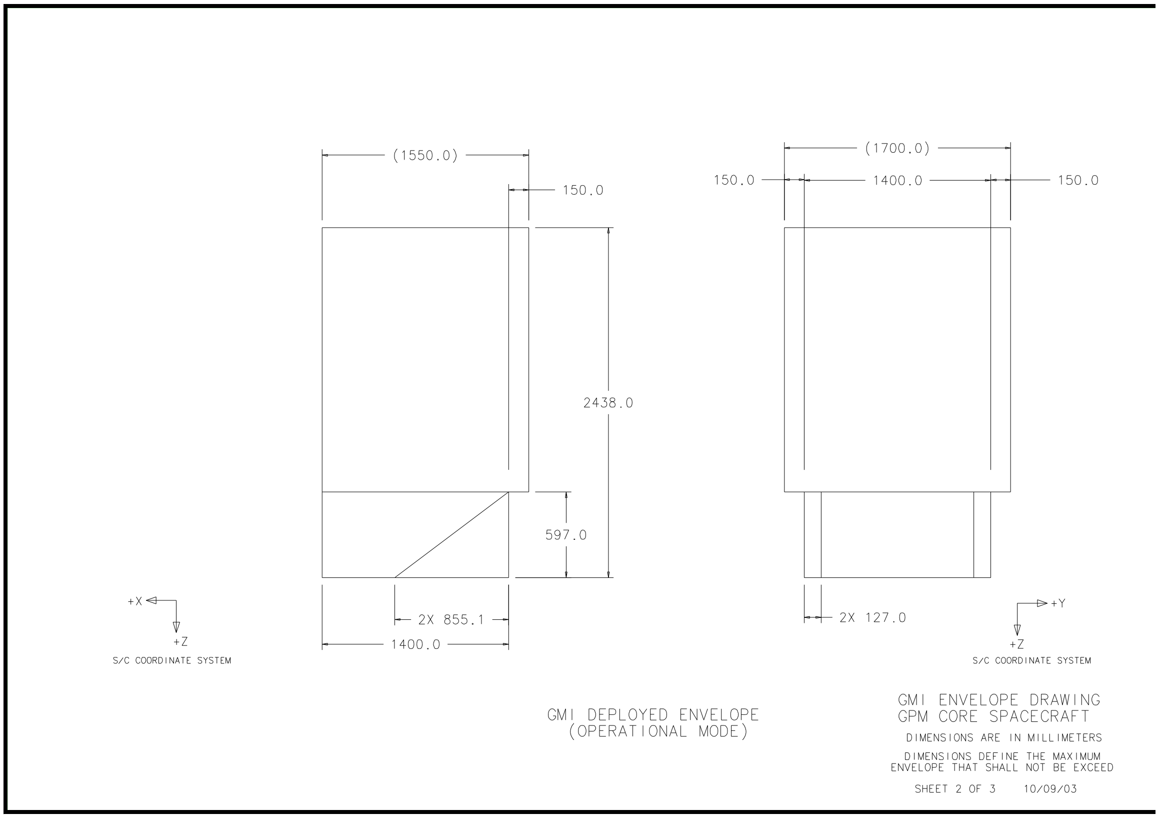


Figure 4-5. Available Envelope During GMI Operational Mode

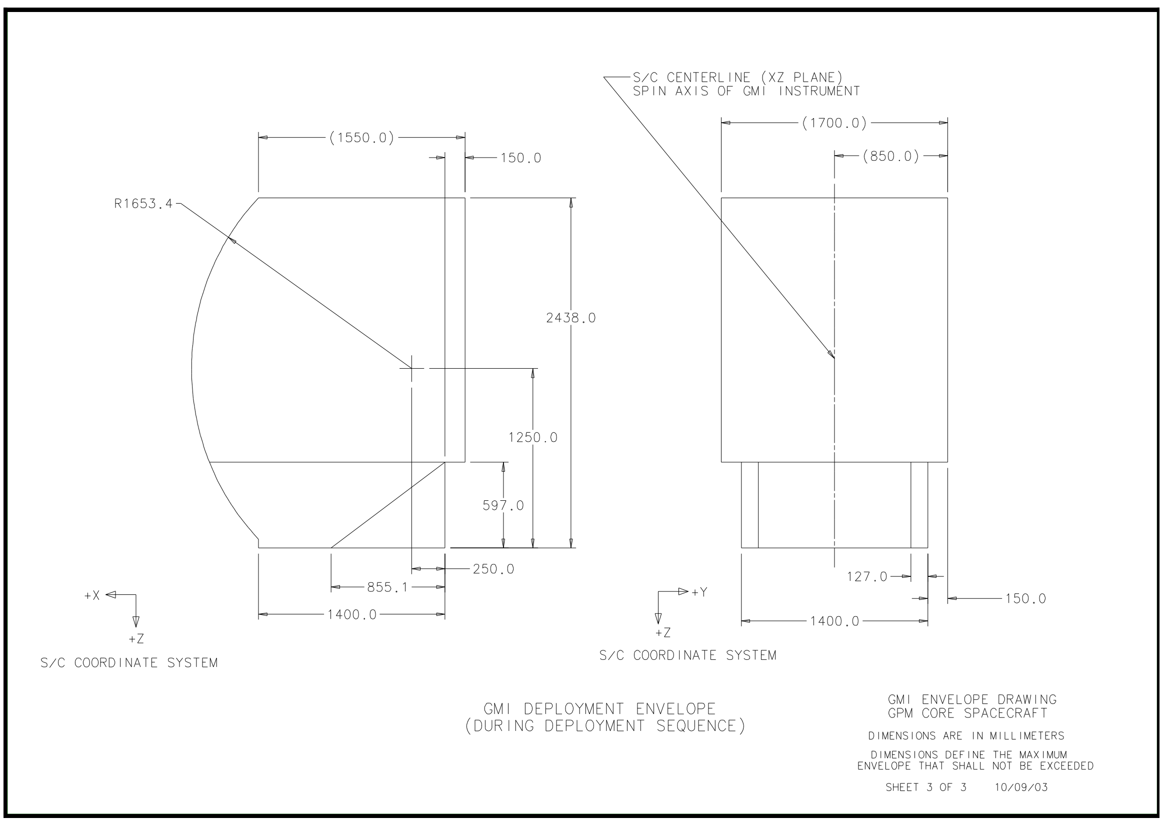


Figure 4-6. Available Envelope During GMI Deployment Sequence

Verification: The contractor shall verify this requirement by measurement.

4.2.2 Instrument Mass Allocation (36-122)

The total instrument mass, including any momentum compensation, deployment mechanisms, interface hardware, and thermal insulation, shall not exceed 100 kilograms. In recognition that different deployment scenarios are possible between the Core and Constellation spacecraft, additional mass allocation may be provided for the deployment mechanism on the Constellation spacecraft. Any additional mass allocation for the Constellation deployment mechanism shall require NASA concurrence.

Verification: The contractor shall verify this requirement by measurement.

4.2.3 GMI Instrument/Attitude Control System Interactions

4.2.3.1 Uncompensated Angular Momentum (36-123)

The uncompensated angular momentum generated by the GMI shall not exceed 0.25 N-m-s.

Verification: The contractor shall verify this requirement through analysis and through demonstration.

4.2.3.2 Uncompensated Startup and Shutdown Torque (36-124)

The maximum GMI uncompensated rotation startup and shutdown torque shall not exceed 0.025 N-m.

Verification: The contractor shall verify the uncompensated startup torque requirement by analysis and demonstration.

4.2.3.3 Dynamic Unbalance (36-125)

The dynamic unbalance of the rotating portion of the GMI shall be no more than 5.5×10^{-2} kg-m^2. This value refers to the off-diagonal elements of the inertia tensor, also known as the products of inertia.

Verification: The contractor shall verify this requirement by test.

4.2.3.4 Static Unbalance (36-126)

The static unbalance, also known as the first mass moment, of the instrument shall be no more than 3.2×10^{-2} kg-m.

Verification: The contractor shall verify this requirement by test.

4.2.4 Mechanisms

4.2.4.1 Deployment (36-127)

The contractor may choose to incorporate deployment mechanisms for the antenna main reflector and other systems as deemed necessary. Deployments shall occur on receipt of instrument commands issued by the spacecraft over the 1553 bus. Positive indication of full deployment (as opposed to kick-off) shall be provided to the spacecraft. The instrument shall employ redundant deployment mechanisms. The contractor shall report the time necessary for completing deployment. Power for deployment mechanisms shall be drawn from the GMI operational power service. Transient currents due to mechanism actuation shall adhere to Requirement 36-97 Turn-On Transient Current.

Verification: The contractor shall verify this requirement by demonstrating the instrument deployment mechanisms under conditions representing the most probable environment of flight. The contractor shall verify the function of the deployment mechanisms by testing them at temperature extremes 10 degrees C beyond the range of expected flight temperatures. Note: In addition, GMI deployment mechanisms will be demonstrated during observatory-level testing.

4.2.4.2 Deployment Circuitry (13-207)

The instrument shall include electrical and electronic circuitry necessary for conducting GMI deployments. The instrument shall include independent driver circuits for each release actuator, providing redundancy.

Verification: This requirement shall be verified by inspection of design documents.

4.2.4.3 Motor Stall Vulnerability (36-128)

No damage shall occur if the scan drive motor is placed in a powered, locked-rotor condition for up to 30 minutes. This requirement applies to both ambient air and vacuum pressure conditions.

Verification: The contractor shall verify this requirement by analysis.

4.2.4.4 Motor Type (36-129)

The scan drive motor(s) and any momentum compensation motor(s) shall not use brushes or contacting positions sensors.

Verification: The contractor shall verify this requirement by inspection.

4.2.4.5 Torque and Force Margin (13-200)

All mechanisms on the GMI shall be designed with positive torque margin (TM), TM > 0. For linear devices, the term 'force' shall replace 'torque' in this requirement. For determining torque margin, the contractor shall use Factors of Safety of 1.50 for torques that are well understood (FS_k) and Factors of Safety of 2.0 for torques that are variable or less understood (FS_v). The vendor shall use the following definition of torque margin:

$$\mathbf{TM = \{ T_{avail} \ / \ (FS_k \times \Sigma T_{known} + FS_v \times \Sigma T_{variable})\} - 1}$$

Equation 4-1

Where:

T_{avail} = Minimum available torque or force generated by the mechanism at worst case environmental conditions at any time in its life. If motors are used in the system, T_{avail} shall be determined at the output of the motor, not including gear heads or gear trains at its output based on minimum supplied motor voltage. T_{avail} similarly applies to other actuators such as springs, pyrotechnics, solenoids, heat actuated devices, etc.

ΣT_{known} = Sum of the fixed torques or forces that are known and quantifiable such as accelerated inertias, and not influenced by friction, temperature, life, etc. A constant Factor of Safety is applied to the calculated torque.

$\Sigma T_{variable}$ = Sum of the torques or forces that may vary over environmental conditions and life such as static or dynamic friction, alignment effects, latching forces, wire harness loads, damper drag, variations in lubricant effectiveness, including degradation or depletion of lubricant over life, etc.

Verification: The contractor shall verify this requirement by test and analysis. The torque margin shall be tested both before and after instrument environmental tests. The torque margin will be tested again at observatory-level integration.

4.2.5 Mounting and Alignment Provisions

4.2.5.1 Mounting Interface (36-130)

The mounting interface location of the GMI instrument shall be in accordance with the GMI envelope requirements of Figures 4-4, 4-5, and 4-6. The GMI contractor shall furnish all mounting hardware and drill fixtures or templates. The contractor shall ensure that mounting materials are compatible with the GMI to spacecraft interface. Final specifications for the the mounting interface location, and the locations for separately mounted components, will be defined within the Interface Control Document.

Verification: The contractor shall verify this requirement through demonstration.

4.2.5.2 Use of Metric Units (36-131)

The external dimensions of the GMI instrument, mounting hole locations, and any other mechanical interfaces to the spacecraft shall be metric. GMI instrument mounting interface hole sizes and fasteners (bolts, shear pins, and helical inserts) shall be English. Any portion of the GMI instrument based on existing designs may be exempt from the metric requirements. All drawings shall be dimensioned in metric units.

Verification: The contractor shall verify this requirement by inspection.

4.2.6 Accessibility and Maintainability (36-132)

The design of the GMI shall permit accessibility to test points, connectors, and components that may require adjustment. This accessibility requirement shall apply during integration of the GMI onto the spacecraft and during pre-launch tests once integrated onto the spacecraft. Any special tools required for servicing or adjusting the GMI shall be delivered with the instrument. All field-removable parts shall be uniquely keyed to insure proper re-assembly and alignment.

Verification: The contractor shall verify this requirement by inspection and demonstration.

4.2.7 Protection and Handling (36-133)

Sensitive parts of the instrument, such as the scanning antenna reflector, cold sky reflector, calibration target(s), and optical alignment reference(s) shall have protective covers to provide protection from handling and contamination during ground activities.

Verification: The contractor shall verify this requirement through inspection.

4.2.8 Materials

4.2.8.1 De-Orbit Surviving Materials (36-135)

In order to limit debris re-entry survival, GMI shall contain no more than a total of four individual parts satisfying either of the following two conditions: (1) Individual parts with a melting point exceeding 1000°C and any linear dimension exceeding 0.20 m. (2) Individual parts with a mass greater than 3.0 kg of stainless steel alloys, 1.0 kg of titanium alloys, 1.0 kg of beryllium alloys, 10.0 kg of aluminum alloys, or 1.0 kg of any material with a melting point greater than 1000°C.

Verification: The vendor shall provide geometry and material information to support NASA's orbital debris assessment calculations. All parts exceeding the required thresholds shall be identified within the overall geometry of the GMI.

4.2.9 Strength Qualification

4.2.9.1 Protoflight and Flight Unit Qualification (36-136)

The first production unit GMI shall be qualified to protoflight level as detailed in Table 4-1. The follow-on GMI unit(s) shall be qualified to acceptance level as detailed in Table 4-1.

Table 4-1. Structural Strength Test Factors and Durations

Table 4-1 Structural Strength Test Factors and Durations

Test	Protoflight / Qualification (1st Unit)	Acceptance (2nd Unit)
Structural Loads		
Level	1.25 X Limit Load	Limit Load
Duration Centrifuge or Sine Burst(1)	 30 Seconds or 5 Cycles Full Level	 30 Seconds or 5 Cycles Full Level
Acoustic		
Level	Limit Level + 3 dB	Limit Level
Duration	1 Minute	1 Minute
Random Vibration		
Level	Limit Level + 3 dB	Limit Level
Duration	1 Minute / Axis	1 Minute / Axis
Sine Vibration		
Level	1.25 X Limit Level	Limit Level
Sweep Rate(2)	4 Octaves / Minute / Axis	4 Octaves / Minute / Axis

Notes:

(1) Sine burst testing shall be done at a frequency sufficiently below primary resonance to ensure rigid body motion.

(2) If not specified differently, these sine sweep rates shall apply for verification testing.

Hardware Definitions as found in GEVS -SE:

Prototype Hardware: This is hardware of a new design. The hardware is subject to a design qualification test program. It is not intended for flight.

Flight Hardware: Hardware to be used operationally in space. It includes the following subsets of hardware:

a. **Protoflight Hardware:**
This is flight hardware of a new design. The hardware is subject to a qualification test program that combines elements of prototype and flight acceptance verification; that is, the application of design qualification test levels and flight acceptance test durations.

b. **Follow-On Hardware:**
Flight hardware built in accordance with a design that has been qualified either as prototype or as protoflight hardware; follow-on hardware is subject to a flight acceptance test program.

c. **Spare Hardware:**

Verification: The contractor shall verify the requirements for the protoflight and acceptance level strength qualification through environmental testing at the contractor's facilities prior to delivery to NASA.

4.2.9.2 Structural Stress Analysis Factors of Safety (36-137)

The instrument structure shall possess positive margins of safety (MS) for both yield and ultimate deformation per the design factors of safety provided in Table 4-2. Positive margin of safety is defined below.

$$MS = \frac{\text{(Allowable Stress or Load)}}{\text{(Factor of Safety X Applied Limit Stress or Load)}} - 1 > 0$$

Equation 4-2

Table 4-2. GMI Stress Analysis Factors of Safety

Structural Material	Design Factor of Safety	
	Yield	Ultimate
GMI Structure - metallic	1.25	1.4
GMI Structure – beryllium	1.4	1.6
GMI Structure – composite	N/A	1.4
Mechanical GSE	3.0	5.0

Verification: The contractor shall verify this requirement by providing a final stress report.

4.3 THERMAL REQUIREMENTS

4.3.1 General Thermal Requirement (36-138)

The GMI instrument shall be responsible for independently controlling its thermal performance. The instrument shall be designed to insure satisfactory operation and stable calibration of the instrument under the thermal environments of both the Core and Constellation spacecraft. The instrument shall include all necessary thermostatically-controlled heaters, radiator surfaces, and thermal blanketing, including any additional thermal blankets which may be needed to interface with the spacecraft thermal blankets. Heater power allocations are described in Power Consumption (requirement 36-104).

Verification: The contractor shall verify this requirement through analysis and testing.

4.3.2 Spacecraft Thermal Interface

4.3.2.1 Spacecraft Thermal Interface (36-139)

GMI shall be designed such that there will be a maximum conducted heat flow of no more than 5 Watts between the GMI and the instrument mounting surface on the spacecraft.

Verification: The contractor shall verify this requirement through analysis and/or testing.

4.3.2.2 Spacecraft Normal Mission Mode Beta Angle (36-140)

Based on the GPM Core orbit, the beta angle will vary over time between -90 and +90 degrees. The GMI instrument shall operate within specification under these solar aspect conditions. The Core spacecraft will perform periodic 180 degree yaw maneuvers to maintain one side of the spacecraft with a cold sky orientation.

Verification: The contractor shall verify this requirement through analysis and through a thermal balance test to verify the model.

4.3.2.3 Spacecraft Interface Temperature (36-142)

The spacecraft-to-instrument baseplate (instrument mounting surface) temperature ranges from -25 degrees C to +50 degrees C. The GMI shall meet all performance requirements for this range of interface temperatures.

Verification: The contractor shall verify this requirement through analysis and/or testing.

4.4 MAGNETIC REQUIREMENTS

4.4.1 Instrument Magnetic Characteristics (36-143)

The magnetic flux density (magnetic induction) due to the GMI instrument shall be no more than 100 nanoTesla at a distance of 1.0 m from the instrument center-of-gravity and at 1.0 m from the location of the GMI angular momentum compensation device. These values represent the distance to the observatory three-axis magnetometer [Figure TBS]. This requirement shall be interpreted as the free-space magnetic flux density and shall include the total magnetic flux density due to permanent field, induced field, and the fields resulting from electrical currents in the instrument.

Verification: The contractor shall verify this requirement through measurement at the contractor's facilities. The magnetic flux density shall again be measured at NASA with the instrument integrated on the spacecraft.

4.4.2 Spacecraft Generated Magnetic Fields (36-144)

Magnetic torquer bars are used to control spacecraft angular momentum and are a part of the spacecraft attitude control system. Each torquer bar is rated at 225,000 pole-cm.

The nearest torquer bar is [TBD] cm from the GMI spin axis on the Core spacecraft and [TBD] cm on the Constellation spacecraft. There shall be no effect upon the performance of the GMI during the operation of the magnetic torquers. TBDs shall be defined in the GMI ICD.

Verification: The contractor shall verify by analysis that the instrument is insensitive to the fields generated by the torquer bars. In addition, this requirement shall be verified by demonstration during spacecraft integration and testing at NASA.

4.5 GMI MODES

4.5.1 GMI Modes (36-528)

GMI shall have, as a minimum, the following modes: GMI Operational Mode, GMI Off Mode, GMI Standby Mode, GMI Engineering/Diagnostic Mode, and Ground Test Mode.

Verification: The contractor shall verify through demonstration that all identified GMI modes behave in accordance with respective mode requirements. The demonstrations shall include transitions between modes as expected on-orbit.

4.5.2 GMI Operational Mode

4.5.2.1 Design for Continuous Operation (36-145)

The instrument shall be designed to operate in the GMI Operational Mode continuously over the full design life.

Verification: The contractor shall verify through analysis of design, demonstration, and spaceflight heritage that the GMI is capable of operating in the Operational Mode continuously over the design life.

4.5.2.2 Full Functional Configuration (36-146)

The instrument shall be in full functional configuration during GMI Operational Mode.

Verification: The contractor shall verify through demonstration that the GMI is fully functional in the Operational Mode.

4.5.2.3 Collection of Measurement and Housekeeping Data (36-147)

The instrument shall produce, and transmit to the spacecraft, science and housekeeping data records during the GMI Operational Mode.

Verification: The contractor shall verify through demonstration that GMI science and housekeeping data records are collected and transmitted in the Operational Mode.

4.5.2.4 Calibration (36-148)

The instrument shall produce calibration measurements, and place the data into the science data record, once per scan during Operational Mode.

Verification: The contractor shall verify through demonstration that on-orbit scanning calibrations are done during the Operational Mode.

4.5.3 GMI Off Mode

4.5.3.1 No Operational Power (36-149)

The GMI shall be capable of entering the GMI Off Mode from all other modes. In the GMI Off Mode, no operational power will be supplied to the instrument. Survival heater power will be available to the instrument.

Verification: The contractor shall verify through demonstration that the instrument is de-energized, except for survival heaters, during GMI Off Mode.

4.5.3.2 Electronics and Mechanical Systems Off (36-150)

In the GMI Off Mode the antenna and spun electronics assembly and any instrument-provided momentum compensation devices shall be stationary, and all subsystems shall be turned off with survival heaters enabled.

Verification: The contractor shall demonstrate that the antenna and momentum compensation devices cease rotation once the GMI is placed in the Off Mode.

4.5.3.3 Power Off Command (36-152)

The instrument shall prepare for GMI Off Mode upon receipt of a Power Off Command from the spacecraft over the MIL-STD-1553-B bus. Upon complete cessation of rotation of the spun section of the instrument and momentum compensation devices, and after completing all other preparations for power removal, the instrument shall notify the spacecraft over the MIL-STD-1553-B bus that operational power may be removed. The spacecraft reserves the right to remove operational power prior to the instrument's full preparations for shut-down. In the event of unanticipated operational power removal, requirements on uncompensated momentum (36-123), torque generation (36-124), and motion cessation time limit (36-151) are waived.

Verification: The contractor shall verify through inspection that the design incorporates a powering-down procedure for the antenna scan drive and momentum compensation device and through demonstration that motion cessation is complete within the warning period.

4.5.3.4 Time Limit for Rotating System Spin Down (36-151)

The spun instrument sections and any momentum compensation devices shall complete motion cessation within 10 minutes of receipt of the Power Off Command.

Verification: The contractor shall verify this requirement through demonstration.

4.5.4 GMI Standby Modes

4.5.4.1 Standby Subordinate Modes (13-203)

The GMI Standby Modes shall consist of two subordinate modes: GMI Standby/Non-Rotation and GMI Standby/Continued Rotation

Verification: The contractor shall verify this requirement by demonstration.

4.5.4.2 Standby/Non-Rotation Mode (13-206)

There shall be no motion associated with the instrument and any GMI-provided momentum compensation devices while the instrument is in the Standby/Non-Rotation Mode.

Verification: The contractor shall verify this requirement by demonstration.

4.5.4.3 Standby/Continued Rotation Mode (36-156)

In the GMI Standby/Continued Rotation Mode the antenna and spun electronics assembly and any GMI-provided momentum compensation shall continue rotating at their nominal rate.

Verification: The contractor shall demonstrate that the sensor antenna, momentum compensation, and spun electronics continue rotation during GMI Standby Mode while other subsystems are de-energized.

4.5.4.4 Status of Science and Housekeeping Data in Standby Modes (36-155)

In the GMI Standby Modes GSDR will not be created. In the GMI Standby Modes GHDR shall continue to be created and transferred to the spacecraft at the nominal rate.

Verification: The contractor shall demonstrate that while in the GMI Standby Mode, the instrument creates and transfers to the spacecraft only housekeeping data records.

4.5.4.5 Commanded to Enter Standby Mode (36-157)

The GMI shall enter the respective Standby Mode when commanded.

Verification: The contractor shall verify this requirement by demonstration.

4.5.4.6 Return to Operational Mode from Standby (36-158)

The GMI shall return to Operational Mode when commanded.

Verification: The contractor shall demonstrate that the return to GMI Operational Mode from the GMI Standby Mode is initiated only after the appropriate command from the spacecraft.

4.5.5 GMI Engineering/Diagnostic Mode (36-159)

The GMI Engineering/Diagnostic Mode shall allow troubleshooting and software updates (e.g., if a programmable processor is employed). Diagnostic data records containing supplemental instrument engineering and diagnostic information shall be provided during this mode. The GMI Engineering/Diagnostic Mode shall permit diagnostic investigation into instrument status beyond what is available from the housekeeping data records.

Verification: The contractor shall verify through demonstration that diagnostic data records, troubleshooting, and software updates (if a programmable processor is employed) are possible during the GMI Diagnostic Mode.

4.5.6 Ground Test Mode (4-763)

The GMI Ground Test Mode shall provide a means to test GMI electronics without the system spinning. GMI shall generate science and housekeeping telemetry in this mode.

Verification: The contractor shall verify this requirement by demonstration.

4.5.7 Additional GMI Modes (36-160)

The contractor shall recommend to NASA additional GMI-specific modes of utility. Examples of additional modes may include, but are not limited to, Test Mode, Storage Mode, Transport Mode, Pre-Launch Mode, Launch and Ascent Mode, Deployment and Initialization Mode, and Calibration and Validation Mode.

Verification: The contractor shall verify through inspection of design documents that additional GMI modes are incorporated.

4.5.8 Transition Between GMI Modes (36-161)

The contractor shall include in the GMI Instrument design restricted and permitted transitions between different GMI Modes (e.g., from GMI Off Mode, the GMI may need to enter the GMI Standby Mode prior to entering the GMI Operational Mode).

Verification: The contractor shall verify this requirement by demonstrating the capability of the GMI to transition between the defined modes in a controlled manner and that restricted mode transitions are not possible.

4.6 ORBITAL ENVIRONMENT

4.6.1 Orbital Characteristics (36-162)

GMI shall be designed to operate in both a 407 km, 65 degree inclination orbit, and a 635 km, Sun-synchronous orbit.

Verification: The contractor shall verify through inspection of design documentation that the two operational environments are addressed for a single GMI design.

4.6.2 Radiation (36-163)

The GMI shall not degrade beyond specification when operating in a space radiation environment characteristic of a three-year design life at a 650 km, Sun-synchronous or a 407 km, 65 degree inclination orbit.

Verification: The contractor shall verify this requirement through analysis and/or testing.

4.6.3 Atomic Oxygen (36-164)

GMI performance shall not be degraded beyond specification by an anticipated atomic oxygen fluence of 2.47×10^{22} atoms/cm^2. For spinning surfaces, with an axis of rotation normal to the spacecraft velocity vector, use 7.86×10^{21} atoms/cm^2 (i.e. reduction by a factor of $1/\pi$).

Verification: The contractor shall verify this requirement through analysis and/or testing.

4.6.4 Pressure (36-165)

The GMI instrument shall be designed to operate within specification at atmospheric pressure, during instrument thermal vacuum testing, spacecraft thermal vacuum testing, and while exposed to a hard vacuum of 350 km altitude or above.

Verification: The contractor shall verify this requirement through analysis and through vacuum testing of the GMI.

4.6.5 Sun Impingement (36-166)

The GMI, in any of its modes, shall withstand, without damage, Sun impingement at any arbitrary incidence angle for up to five minutes.

Verification: The contractor shall verify this requirement through analysis of stowed and deployed GMI configurations in all potential modes.

4.7 LAUNCH LOADS

4.7.1 Launch Loads General Requirements (36-529)

The GMI instruments shall meet all performance and implementation requirements after subjection to the launch loads associated with their respective GPM Core and Constellation spacecraft launch vehicles. The GMI instruments shall be qualified to a single loading requirement which envelopes the two launch vehicles. [TBR: The following load environments are preliminary, are intended to envelope the potential launch vehicles, and will be updated as launch vehicle information becomes available.]

Verification: The contractor shall verify this requirement by analysis and test.

4.7.2 GMI Design Load Limit Factors (36-167)

The GMI shall be designed to withstand 15 g in any single axis applied at the center-of-gravity.

Verification: The contractor shall verify by test in accordance with the levels and durations of Structural Loads in Table 4-1.

4.7.3 Design Limit Loads, Separately Mounted Components (4-725)

Components mounted separately from the instrument structure shall be designed to withstand the loads in any single axis applied at the center of gravity as follows:

Mass < 2.0 kg	50.0 g
2.0 kg < Mass < 10 kg	30.0 g
10 kg < Mass < 20 kg	21.0 g
20 kg < Mass	18.0 g

Verification: The contractor shall verify by test in accordance with the levels and durations of Structural Loads in Table 4-1.

4.7.4 Natural Frequency Requirements

4.7.4.1 Stowed Configuration (36-168)

The GMI shall have a fundamental natural frequency greater than 50 Hz in the stowed configuration when hard mounted. With NASA's concurrence, it may be permissible for modes representing less than 10% of the modal effective mass to be characterized by fundamental natural frequencies below 50 Hz.

Verification: The contractor shall verify this requirement by test and corroborate the results with predictions from the structural math model (DID 23). The contractor shall identify and report all modes characterized by frequencies of 75 Hz or less.

4.7.4.2 Stowed Configuration, Separately Mounted Components (4-724)

Components mounted separately from the instrument structure shall have fundamental natural frequencies greater than 100 Hz in the stowed configuration when hard mounted.

Verification: The contractor shall verify this requirement by either test or analysis.

4.7.4.3 Deployed Configuration (36-169)

The GMI shall have a fundamental natural frequency greater than 5.0 Hz in the on-orbit deployed configuration.

Verification: The contractor shall verify this requirement by test.

4.7.5 Integrated Spacecraft Test Environments

4.7.5.1 GMI Random Vibration Environment (36-170)

The GMI shall be designed to withstand the random vibration environment of launch. The anticipated launch vibration environment is enveloped by the acceptance level limits of Figure 4-7.

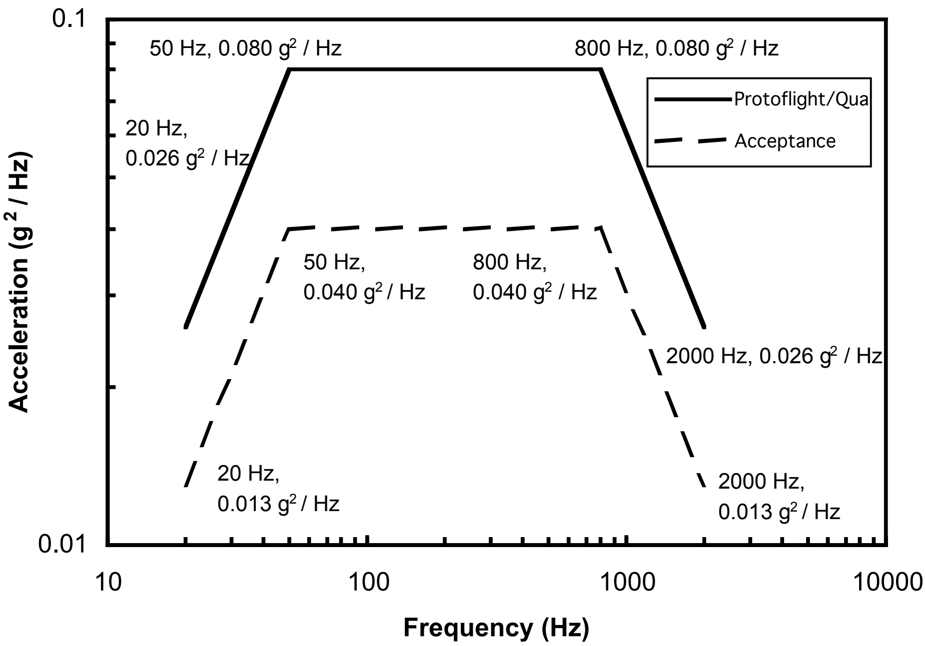


Figure 4-7. Random Vibration Environment for the GMI Instrument

Verification: The contractor shall verify by testing the first GMI unit to the protoflight / qualification level and additional identical units to acceptance level in accordance with the levels and durations of Table 4-1 and Figure 4-7. The overall loading is 10.7 g rms for protoflight/qualification and 7.6 g rms for flight acceptance.

4.7.5.2 Random Vibration Environment for Separately Mounted Components (4-726)

Components mounted separately from the instrument structure shall be designed to withstand the random vibrational environment of launch. The anticipated launch vibration environment is enveloped by the acceptance level limits of Figure 4-8.

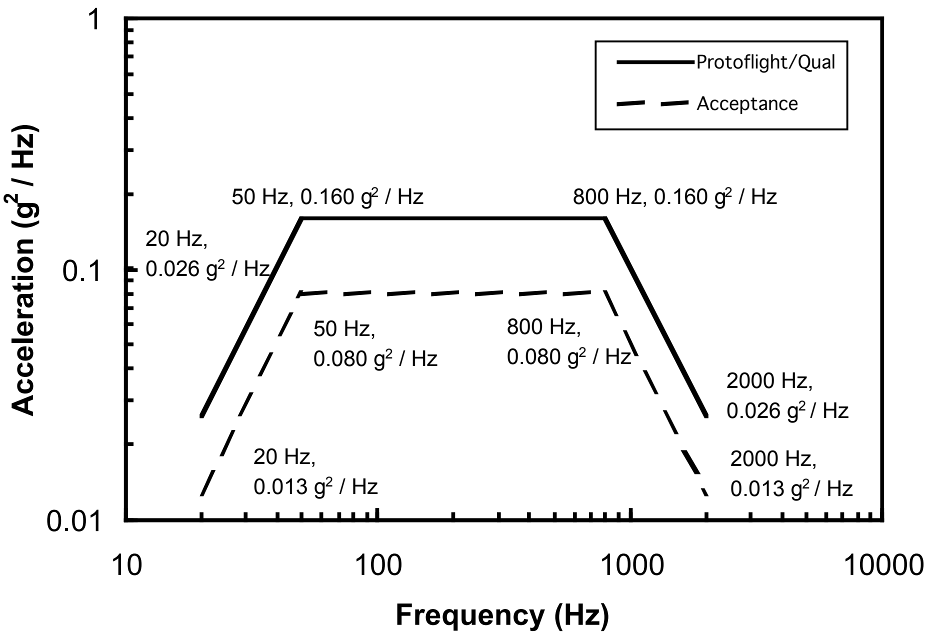


Figure 4-8. Random Vibration Environment for Separately Mounted GMI Components

Verification: The contractor shall verify by testing the separately mounted components of the first GMI unit to the protoflight / qualification level and testing separately mounted components of additional units to acceptance level in accordance with the levels and durations of Table 4-1 and Figure 4-8. The overall loading is 14.1 g rms for protoflight/qualification and 10.0 g rms for flight acceptance.

4.7.5.3 Sine Vibration Environment (4-727)

The GMI shall be designed to withstand the sine vibration environment of launch as specified by the following limit levels.

Frequency	Protoflight / Qualification Level	Acceptance Level
5 – 50 Hz	TBD	TBD

Verification: The contractor shall verify by test in accordance with the levels and durations for Sine Vibration in Table 4-1. Note: In addition, the GMI will be subjected to sine vibration environment testing after integration onto the observatory.

4.7.5.4 Sine Vibration Environment for Separately Mounted Components (4-728)

Components mounted separately from the instrument structure shall be designed to withstand the sine vibration environment of launch as specified by the following limit levels.

Frequency	Protoflight / Qualification Level	Acceptance Level
5 – 50 Hz	TBD	TBD

Verification: The contractor shall verify by test in accordance with the levels and durations for Sine Vibration in Table 4-1. Note: In addition, separately mounted GMI components will be subjected to sine vibration environment testing after integration onto the observatory.

4.7.5.5 Acoustic Environment (36-171)

The GMI, including any components mounted separately from the instrument structure, shall withstand the acoustic environment limit levels expected during launch and provided in Table 4-3.

Table 4-3. Acoustic Environment Spectrum and Levels

Center Frequency (Hz) Octave Bands	Protoflight/Qual Sound Pressure Level (dB)	Acceptance Sound Pressure Level (dB)
31.5	128	125
63	129.5	126.5
125	134	131
250	136	133
500	131.5	128.5
1000	128	125
2000	123	120
4000	118	115
8000	116	113
OASPL	140.5	137.5

Verification: The contractor shall verify this requirement by analysis or by test. The test levels and durations for acoustic testing are found in Table 4-1 and Table 4-3. Verification of GMI Random Vibration Environment (36-170) and Random Vibration Environment for Separately Mounted Components (4-726) may substitute for an acoustic test if analysis indicates that the random vibration test envelopes the acoustic environment. Note: In addition, the GMI will be subjected to an acoustic environment test after integration onto the observatory as part of observatory-level environmental testing.

4.7.5.6 External Shock Environment (36-172)

The GMI shall be designed to withstand the shock spectrum of Figure [TBS] which envelopes the shock of external events including clamp band release during spacecraft separation, spacecraft solar array deployment, and spacecraft communication antenna deployment.

Verification: The contractor shall verify this requirement by analysis. Note: In addition, GMI will be subjected to external shock events representative of spacecraft separation and subsystem deployments during observatory-level testing.

4.7.5.7 Self-Induced Shock Environment (4-729)

The GMI shall be designed to withstand a shock environment characterized by self-induced shocks from GMI deployment mechanism actuation.

Verification: The contractor shall verify this requirement by test. The GMI shall be subjected to all self-induced shocks a minimum of two times. Note: A minimum of two additional deployments at observatory level will be performed, once after integration, and once after environmental testing.

4.7.6 Pressure Profile Environment (36-173)

The GMI shall withstand without damage the venting pressure profile of launch provided in Figure 4-9 and consistent with profiles provided in the H-IIA User's Manual.

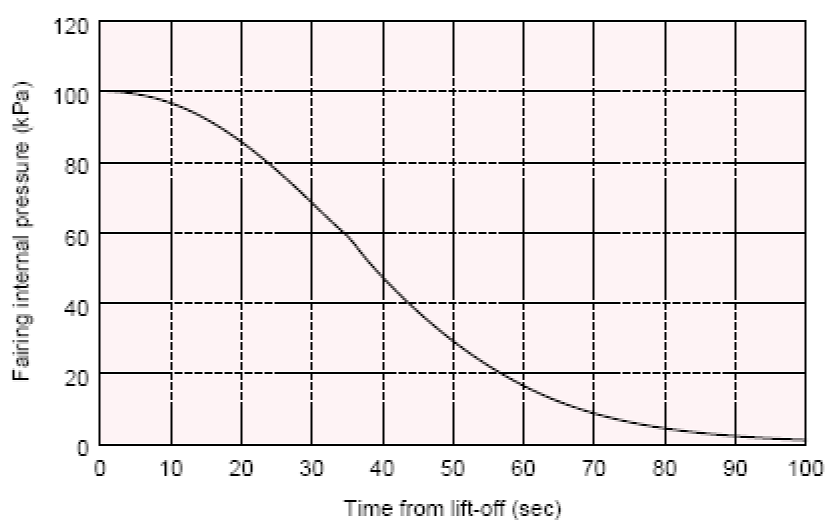


Figure 4-9. Venting Pressure Profile

Verification: The contractor shall verify this requirement through analysis with positive margin for loads equal to twice those induced by the venting profile of Figure 4-9 or shall verify through test with the venting profile of Figure 4-9.

4.8 GROUND OPERATIONS

4.8.1 Ground Support Equipment (GSE) General (36-176)

The GSE shall be designed to support and operate the GMI as a stand-alone item as well as integrated onto a GPM spacecraft. Support includes transportation and storage, mechanical handling, power, command and telemetry processing, thermal control, sensor alignment and calibration under laboratory, integration and test, and pre-launch environments.

Verification: The contractor shall verify this requirement through inspection and demonstration that the GSE exists and functions as intended.

4.8.2 Mechanical Ground Support Equipment (MGSE)

4.8.2.1 Lifting Ground Support Equipment (36-530)

Lifting ground support equipment capacity shall satisfy the following load factors according to the type of lifting device:

Type of MSGE	Load Factor (g)		
	Vertical	Lateral	Longitudinal
Slings	-1.6	N/A	N/A
Dolleys	±1.6	±0.5	±0.5

*Lateral and longitudinal loads are not applied concurrently.

All lifting ground support equipment shall comply with NASA Standard 8719.9.

Verification: The contractor shall verify this requirement through analysis and test using design factors and test factors of safety in accordance with NASA Standard 8719.9.

4.8.2.2 Handling Fixtures (36-177)

The design of instrument handling fixtures shall permit moving the GMI from its shipping/storage container to a work/test station at the observatory integration site and assist with handling and installing the GMI during observatory integration.

Verification: The contractor shall verify this requirement by demonstration.

4.8.2.3 Ground Deployment Test Fixtures (36-178)

The GMI contractor shall design the instrument deployment test fixtures, with inclusion of provisions for gravity negation, allowing full deployment tests to be conducted on the instrument at the spacecraft integration test facilities. The deployment tests will be conducted independently on the instrument as well as after instrument integration onto the GPM spacecraft.

Verification: The contractor shall verify this requirement through demonstration.

4.8.2.4 Templates/Drill Fixtures (36-179)

The drill template or fixture shall contain an optical alignment reference with known relation to the instrument optical alignment reference. Details regarding the drill template design will be specified within the Interface Control Document.

Verification: The contractor shall verify by demonstration that the drill template alignment reference is present and has known relation to instrument alignment reference.

4.8.2.5 Combined Shipping and Storage Containers (36-180)

Shipping and storage containers shall be reusable, water resistant, hermetically sealable, and suitable for both shipping and for long-term storage of the GMI instruments. The containers shall incorporate a capability for purging with dry nitrogen. The containers shall maintain the internal environment to temperatures between 5 and 50 degrees Celsius, relative humidity levels between 10% and 60%, and positive pressure not to exceed two standard atmospheres.

Verification: The contractor shall verify by demonstration that the shipping and storage containers satisfy the required characteristics.

4.8.3 Electrical Ground Support Equipment (EGSE)

4.8.3.1 GMI Ground Operations (36-182)

The contractor shall provide electrical ground support equipment (EGSE) enabling GMI operation while: (1) GMI is independent from the spacecraft (independent operation), and (2) GMI is integrated onto the spacecraft (spacecraft integrated operation). For independent operation NASA will provide to the contractor a spacecraft interface simulator. For spacecraft integrated operation, spacecraft electrical ground support equipment will be employed.

Verification: The contractor shall verify this requirement by demonstration.

4.8.3.2 Independent Operation (13-214)

The GMI EGSE shall operate in conjunction with the spacecraft interface simulator during instrument operations independent of the spacecraft. For communication not managed by the simulator over the MIL-STD-1553-B bus, such as dedicated instrument telemetry, the GMI EGSE shall provide a direct interface to the instrument. The GMI EGSE shall include provision of an external instrument power supply.

Verification: The contractor shall verify this requirement by demonstration.

4.8.3.3 Integrated Operation (36-183)

The GMI EGSE shall operate in conjunction with spacecraft EGSE once the instrument is fully integrated onto the spacecraft during ground testing.

Verification: The contractor shall verify this requirement by demonstration.

4.8.3.4 EGSE Functions (36-184)

The GMI EGSE shall be capable of instrument command and control, real-time capture and processing of GMI housekeeping data, science data, spacecraft-monitored telemetry data, and any engineering or diagnostic data. The GMI EGSE shall be capable of recording and displaying instrument data in processed form.

Verification: The contractor shall verify this requirement by demonstration.

4.8.3.5 Ground Support Software (36-185)

The contractor shall provide software for enabling integration and test activities with the GMI for both independent and spacecraft integrated operation. The software shall provide functions of command generation, telemetry processing, science data processing, diagnostic checking, and display. The software shall be installed on the GMI EGSE and the software shall be compatible Core spacecraft command and telemetry software. Details regarding the Core spacecraft command and telemetry software will be specified within the Interface Control Document.

Verification: The contractor shall verify this requirement by demonstration.

5.0 VERIFICATION REQUIREMENTS

5.1 VERIFICATION PROGRAM (36-186)

The contractor shall establish and maintain an organized program for verifying that the GMI instruments meet all performance, implementation, and mission assurance requirements. The contractor shall refer to Chapter 9 of the GMI MAR for detailed requirements on the verification program.

5.2 VERIFICATION PLAN AND PROCEDURES (36-187)

The contractor shall develop and implement a System Performance Verification Plan in accordance with CDRL 27. The purpose of this plan is to ensure that proper and adequate verification activities are planned for different phases of the instrument development (e.g., card level verification, box/subsystem level verification, system level). For each verification activity, a verification procedure shall be established. Verification procedures shall be reviewed and approved by appropriate individuals to ensure flight hardware integrity is not compromised due to improper or inadequate procedure application.

5.3 VERIFICATION REPORTS (36-188)

All verification activities shall be documented and made available for NASA review. Performance Verification Test Reports shall be submitted in accordance with CDRL 28. All verification reports shall indicate the specific performance or implementation requirement(s) it addresses.

APPENDIX A -- ABBREVIATIONS AND ACRONYMS

ASIST	Advanced System for Integration and Spacecraft Test
CCB	Configuration Control Board
CDRL	Contract Data Requirements List
CE	Conducted Emissions
CFS	Center Frequency Stability
CS	Conducted Susceptibility
DC	Direct Current
DCN	Documentation Change Notice
DPR	Dual-frequency Precipitation Radar
EESS	Earth Exploration Satellite Service
EGSE	Electrical Ground Support Equipment
ELV	Expendable Launch Vehicle
EMC	ElectroMagnetic Compatibility
EMI	ElectroMagnetic Interference
GDR	GMI Data Record
GEVS-SE	General Environmental Verification Specification for STS and ELV Payloads, Subsystems, and Components
GHDR	GMI Housekeeping Data Record
GSDR	GMI Science Data Record
GHz	GigaHertz
GMI	GPM Microwave Imager
GPM	Global Precipitation Measurement
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
H	Horizontal
Hz	Hertz
ICD	Interface Control Document
IFOV	Instantaneous Fields of View
IRWA	Integrated Reaction Wheel Assembly
K	Kelvin
kbps	kilobits per second
MGSE	Mechanical GSE
MHz	MegaHertz
MIL-HDBK	Military Handbook
MIL-STD	Military Standard
MS	Margin of Safety

NASA	National Aeronautics and Space Administration
NEDT	Noise Equivalent Delta Temperature
NIST	National Institute of Standards and Technology
NTIA	National Telecommunications and Information Agency
PPS	Precipitation Processing System
PRA	Probabilistic Risk Assessment
PSE	Power Supply Electronics
RE	Radiated Emissions
RF	Radio Frequency
RFI	Radio Frequency Interference
rms	Root Mean Square
RS	Radiated Susceptibility
RT	Remote Terminal
SSPC	Solid State Power Controller
STD	Standard
T&C	Telemetry and Command
TBD	To Be Determined
TBR	To Be Reviewed
TBS	To Be Supplied
V	Vertical
V	Volts
VSWR	Voltage Standing Wave Ratio
W	Watt

APPENDIX B – HIGH FREQUENCY CHANNELS

The requirements contained in Appendix B shall apply to the incorporation of the High Frequency Channels (i.e., Channels 10 through 13 identified in Table B-1) into the instrument design. Paragraphs B.4.1.1.10, B.4.1.3.4 and B.4.2.2 shall supercede Paragraphs 4.1.1.10, 4.1.3.4 and 4.2.2; all other requirements contained in the GMI Requirements Document shall apply.

The science community will use the measurements obtained with the high frequency channels for research relating to the measurement of light rain and snow.

B.3.1.1.2 High Frequency Channel On-Orbit Operational Life / Design Life

The High Frequency Channels shall be designed to operate on-orbit, within specification, for a minimum of 14 months. This operational duration is also referred to as design life. The 14 months includes two months of on-orbit checkout followed by 12 months of science operation. It is the goal of GPM to achieve the same operational life for the High Frequency Channels as achieved by the GMI instrument (refer to instrument design life, Paragraph 3.1.1.2).

Verification: The contactor shall verify this requirement through a Probabilistic Risk Assessment (PRA) per CDRL 42. Further verification shall be accomplished through on-orbit operational demonstration.

B.3.1.1.3 High Frequency Channel Probability of Success

The Probability of Success for the High Frequency Channels shall have, as a minimum, an 85 percent probability of operation on-orbit, within specification, for the design life of the High Frequency Channels. The calculation for the Probability of Success for the GMI Instrument (Paragraph 3.1.1.3) shall be made without including the High Frequency Channels Probability of Success. The design and implementation of the High Frequency Channels shall be such that any failure mode of these channels shall not reduce the Probability of Success for the GMI Instrument below the value specified in Paragraph 3.1.1.3.

Verification: The contractor shall verify this requirement through a Probabilistic Risk Assessment (PRA) per the Mission Assurance Requirement document and report the analysis per CDRL DID 42.

B.3.1.2 GMI High Frequency Channels

Table B-1. Required GMI High Frequency Channel Set and Required Performance

Chan. #	Center Freq. f_c [GHz]	CFS [MHz] (Stab ±) (Max. (Deviation)	Pass-band Bandwidth B[3] [MHz] (Max.)	Pol.[4]	Integration Time[5] [ms] (for reporting NEDT)	NEDT[5] [K] (Max.)	Antenna 3 dB beam width[6] [degrees] (Max.)
10[1]	166	200	4000 RF	V	2.2	1.5	0.40
11[1]	166	200	4000 RF	H	2.2	1.5	0.40
12[2]	183.31 ± A	100	3500 IF / 7000 RF	V or H	2.2	1.6	0.40
13[2]	183.31 ± B	100	4500 IF / 9000 RF	V or H	2.2	1.5	0.40

A. Abbreviations:
- Freq. = Frequency
- Pol. = Polarization
- V = Vertical
- H = Horizontal
- Stab. = Stability
- CFS = Center Frequency Stability
- K = Kelvin
- GHz = GigaHertz
- MHz = MegaHertz
- DB = deciBel
- NEDT = Noise Equivalent Delta Temperature = Radiometric Sensitivity
- B = Pass-band Bandwidth

B. Remarks Regarding Table B-1:

[1] The channel center frequency and bandwidths for Channels 10 and 11 lie within a band protected by NTIA allocation (Earth Exploration Satellite -- Passive)

[2] Receiver double-sideband operation is assumed for Channels 12 and 13.
For Channel 12, the acceptable range for setting the value of A is 2.9 to 3.1 GHz, with preference at 3.0 GHz.
For Channel 13, the acceptable range for setting the value of B is 7 to 9 GHz, with preference at 9 GHz.

[3] For Channels 12 and 13, NASA prefers narrower pass-band bandwidths than the maximum values. NASA also prefers lower radiometric sensitivity values (NEDT) and recognizes that a design trade is required for optimizing performance when selecting both pass-band bandwidth and radiometric sensitivity.

[4] There is no preference between Vertical and Horizontal linear polarization on Channels 12 and 13. The same polarization shall be used for both Channels 12 and 13.

[5] Radiometric sensitivity is defined in Section 3.1.4. The Integration Times provided are for use in calculating NEDT. Note: These times correspond to motion through one channel 3 dB beam width given a beam width of 0.40 degrees and an antenna rotation rate of 40 rpm. These times are not meant to suggest actual sensor integration times; these times are to be used only for NEDT calculation for comparison to required NEDT of Table B-1.

[6] The beam widths of Channels 10 through 13 shall be designed to a single value and identical to that of Channels 8 and 9.

B.3.1.2.1 Minimum Set of High Frequency Channels

The High Frequency Channels shall include channels 10 through 13 described in Table B-1.

Verification: The contractor shall verify by receiver tests that the operational channels are in agreement with Table 3-1.

B.3.1.2.2 Alternative and Additional Channels for the Measurement of Light Rain and Snow

The contractor may propose the use of alternative and/or additional high frequency channels for the measurement of light rain and snow if their use provides improved sensor performance, improved protection from Radio Frequency Interference (RFI), or for other reasons that may provide best value improvements to NASA. Proposals for alternative and/or additional channels shall include the rationale for the recommendation, and identify the center frequency, stability, width of the pass-band, polarization, calculated Noise Equivalent Delta Temperature (NEDT), antenna 3 dB beam width, and rationale for any use of spectrum not allocated exclusively to the Earth Exploration Satellite Service (EESS).

Verification: The contractor shall verify through analysis and demonstration that the performance of additional and alternate channels meet specification. The contractor shall provide analyses regarding the likelihood that alternate channels will be affected by external radio frequency interference.

B.3.1.7.4.3.2 Along-Scan Sampling for Channels 10 Through 13

For channels 10 through 13 in the along-scan direction there shall be at least 1.0 samples per IFOV (3 dB antenna beam width).

Verification: The contractor shall verify through demonstration and analysis the acquisition of no less than 1.0 samples per channel IFOV for channels 10 through 13.

B.3.1.7.4.4.2 Cross-Scan Sampling for Channels 10 through 13

For channels 10 through 13 in the cross-scan direction there shall be at least one sample within a distance of twice the IFOV (3 dB antenna beam width).

Verification: The contractor shall verify through demonstration and analysis the acquisition of no less than 50 percent spatial coverage in the cross-scan dimensions for channels 10 through 13.

B.4.1.1.10 Power Consumption

For an instrument whose channel set consists of channels 1 through 13, the total power drawn for GMI, from both operational power and survival heater power sources, from the spacecraft shall not exceed 90 W orbital average in the Sensor Operational Mode plus, as appropriate, an additional power allocation of [TBD] W for Channels 10 through 13 that will be added following contract award/modification . When operational power service is removed, the total power drawn shall not exceed 48 W orbital average from the survival heater power service.

Verification: The contractor shall verify by test that for all instrument modes the power consumption at 21 V, 28 V, and 35 V DC does not exceed the specified limits. The contractor shall include analysis for verifying that power consumption over the continuous source voltage range of 21 to 35 V DC does not exceed the specified limit.

B.4.1.3.4 Science Data Telemetry Rate

In the GMI Operational Mode, the GMI shall produce an orbital average science data rate not to exceed 24 kbps plus , as appropriate, an additional [TBD] kbps for Channels 10 through 13 that will be added following contract award/modification.

Verification: The contractor shall verify this requirement through analysis and demonstration.

B.4.2.2 Instrument Mass Allocation

The total instrument mass for an instrument whose channel set consists of channels 1 through 13, including any momentum compensation, deployment mechanisms, interface hardware, and thermal insulation, shall not exceed 100 kilograms plus, as appropriate, an additional [TBD] kilograms for Channels 10 through 13 that will be added following contract award/modification. In recognition that different deployment scenarios are possible between the Core and Constellation spacecraft, additional mass allocation may be provided for the deployment mechanism on the Constellation spacecraft. Any additional mass allocation for the Constellation deployment mechanism shall require NASA concurrence.

Verification: The contractor shall verify this requirement by measurement.